Arthur D. Little, Inc.

HEAT FLOW PROBE PROGRAM

Bendix Contract SC 0242

Case 68647 ______

FLIGHT MODEL #2

2.12 END ITEM INSPECTION AND TEST PROCEDURE

e. Test Procedure No. 0501, Part IV, Rev. F
Thermal Environment Test Procedure Heat
Flow Probe and Electronics for ALSEP Program

CHRONOLOGY OF F2 HFE

THERMAL TEST PROGRAM

Date	Test or Action	Remarks
4/29/68	F2 into ΔT Apparatus	
4/30/68	None	F2-1 Equilibrating
5/ 1/68	F2-1, Test T57A, 245/+2°K	
5/ 2/68	F2-1, Test T57B, 225/+18°K	
5/ 3/68	F2-2, Test T58A1, 225/+18°K	Test Void; Human Error
5/ 4/68	F2-2, Test T58A2, 225/+18°K	
5/ 6/68	F2-2, Test T58B, 245/+2°K F2 HFE Removed from ΔT Apparatus and Placed into K-Apparatus	
5/ 7/68	None	F2 Equilibrating
5/ 8/68	Initiate F2-1, Test K14A(2A)	
5/ 9/68	Complete F2-1, Test K14A(2A) Initiate F2-2, Test K14B(4A)	F2-2 HFE Upper Gradient Bridge Reading 14000 Octal Data Block 3 and 7 during Test K14B
5/10/68	Troubleshooting F2-2 in K-Apparatus	In addition to 14000 octal malfunction on lower gradient bridge of F2-2, we had ETS-printer line skipping problem.
5/13/68	F2 HFE Removed from K-Apparatus and Placed in Isothermal Tube	
5/14/68	Troubleshooting F2-2	
5/15/68	" "	
5/16/68	" "	

Date	Test or Action	Remarks
5/17/68	Troubleshooting F2-2	
5/18/68	" "	
5/20/68	" "	
5/21/68	" "	
5/22/68	" "	F2-2 14000 Octal Malfunction Traced to Electronics
5/23/68	Returned F2 Electronics to Gulton	
9/ 5/68	F2 Electronics Returned to ADL	
9/ 9/68	F2 HFE Probe-Electronics Hardwiring completed; F2 HFE Placed into ΔT Apparatus	
9/10/68	None	F2-1 Equilibrating
9/11/68	F2-1, Test T61A, 245/+2°K Removed F2 HFE from ΔT Apparatus	Lower Ring Bridge Signal Erratic
9/12/68	Troubleshooting F2-1 Lower Ring Bridge	Peacock of BxA and Wirenious of Gulton at ADL
9/13/68	Troubleshooting F2-1	Broken Lead in F2 Electronics Located; Lead Repaired
9/14/68	F2 HFE Placed into ΔT Apparatus	F2-1 Equilibrating
9/16/68	F2-1, Test T62A, 245/+2°K	Test Aborted Because of Apparatus LEH Power Supply Instability
9/20/68	F2-1, Test T62B, 245/+2°K Removed F2 HFE from ΔT Apparatus and Placed into Manufacturing Storage	BxA Instructed ADL to Initiate Acceptance Tests with F2S HFE
9/27/68	F2 HFE Removed from Storage and Placed into ΔT Apparatus	F2-1 Equilibrating

Date	Test or Action	Remarks
9/30/68	None	F2-1 Equilibrating
10/ 1/68	None	F2-1 Equilibrating
10/ 2/68	F2-1, Test T65A, 225/+18°K Removed F2-1 and Inserted F2-2 ΔT Apparatus	F2-2 Equilibrating
10/ 3/68	F2-2, Test T66A, 225/+18°K	F2-1 Lower Gradient Bridge Outside Acceptance Cirteria TWX T-2282 to BxA for Notification
10/ 4/68	None	F2-2 Equilibrating
10/ 7/68	F2-2, Test T66B, 245/+18°K	ADL TWX T-2284 to BxA Recommended Action on F2-1 LGB
10/ 8/68	None	
10/ 9/68	None	
10/10/68	None	
10/11/68	None	
10/14/68	None	
10/15/68	None	F3 HFE Removed from K-Apparatus-Ready for F2 HFE
10/16/68	F2-1 Troubleshooting Test T67A, 205/-2°K	
10/17/68	None	Recommended Action to BxA F2-1
10/18/68	F2 HFE Removed from ΔT Apparatus and Placed into K-Apparatus	F2 Equilibrating Waiting BxA Instructions on F2-1
10/21/68	None	F2 Equlibrating Waiting BxA Instruction on F2-1
10/22/68	None	Waiting BxA Instructions on F2-1

Date	Test or Action	Remarks
10/24/68	Remove F2 HFE from K-Apparatus	
10/25/68	Disconnect F2-1 Probe from F2 electronics and place into ΔT Apparatus	Per Bendix Twx S-2816
11/ 1/68	F2-1, Test T69A3, 245/+2°K	W/o Electronics
11/ 4/68	F2-1, Test T69B, 225/+18°K	W/o Electronics
11/ 5/68	F2-1, placed into bonded stores	
11/ 7/68	F2 Electronics returned to Gulton	Per Bendix Twx S-2948
11/29/68	F2 Electronics received from Gulton	
12/ 6/68	ETS modified by BxA for operation with F2 electronics	
12/ 9/68	F2-1, Test T73A, 245/+2°K	Acceptance
12/11/68	F2-1, Test T73B, 225/+18°K	Acceptance
12/13/68	F2-2, Test T74A, 225/+18°K	Acceptance
12/16/68	F2-2, Test T74B, 245/+2°K	Acceptance
1/ 7/69	F2-1, Test K17A	Acceptance
1/ 8/69	F2-2, Test K17B	Acceptance
1/10/69	F2-1, Test K17C	Acceptance
1/15/69	F2-2, Test K17D	Acceptance
1/16/69	F2-1 and -2, Test 17E	Acceptance
1/17/69	F2-1 and -2, Test TC/F2	Acceptance

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THERMAL TEST SUMMARY

January 17, 1969

Flight 2 Model, Probe No. 2

TEST NO.	DATE	TEST DESCRIPTION	ELECTRONICS	TEST TYPE	REMARKS
T36A	1/ 8/68	205/2°K Negative Gradient	None	Acceptance	
T36B	1/ 9/68	205/0°K Neutral Gradient	None	Acceptance	
T36C	1/10/68	245/2°K Positive Gradient	None	Acceptance	
T58A	5/ 4/68	225/18°K Positive Gradient	F2	(Acceptance)	
T58B	5/ 6/68	245/2°K Positive Gradient	F2	(Acceptance)	
T66A	10/ 3/68	225/18°K Positive Gradient	F2	(Acceptance)	
T66B	10/ 7/68	245/2°K Positive Gradient	F2	(Acceptance)	
T74A	12/13/68	245/18°K Positive Gradient	F2	Acceptance	
T74B	12/16/68	245/2°K Positive Gradient	F2	Acceptance	
K17B(4A)	1/ 8/69	Evacuated Beads, 225°K	F2	Acceptance	
K17D	1/15/69	GN_2 Filled Beads, 225°K	F2	Acceptance	
K17E	1/16/69	Heater Checkout	F2	Acceptance	
TC/F2	1/17/69	Ref. Junction and T.C. Test	F2	Acceptance	

NOTE:

The test type given by an acceptance in brackets indicates that the test was originally run as an acceptance test, but, because of system anomalies, the tests were rerun and are superseded by unbracketed acceptances.

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THERMAL TEST SUMMARY

Flight 2 Model, Probe No. 1

TEST NO.	DATE	TEST DESCRIPTION	ELECTRONICS	TEST TYPE	REMARKS
T35A	1/ 2/68	205/2°K Negative Gradient	None	Acceptance	
T35B	1/ 4/68	225/0°K Neutral Gradient	None	Acceptance	
T35C	1/ 5/68	245/2°K Positive Gradient	None	Acceptance	
T57A	5/ 1/68	245/2°K Positive Gradient	F2	(Acceptance)	
T57B	5/ 2/68	225/18°K Positive Gradient	F2	(Acceptance)	
K14A(2A)	5/ 8/68	Evacuated Beads, 225°K	F2	(Acceptance)	
T61A	9/11/68	245/2°K Positive Gradient	F2	(Acceptance)	F2 Electronics Malfunction
T62A	9/16/68	245/2°K Positive Gradient	F2	(Acceptance)	Apparatus Instability
T62B	9/20/68	245/2°K Positive Gradient	F2	(Acceptance)	
T65A	10/ 2/68	225/18°K Positive Gradient	F2	(Acceptance)	
T67A	10/16/68	205/2°K Negative Gradient	F2	Troubleshoot	
T69A	10/30/68	245/2°K Positive Gradient	None	Troubleshoot	
T69B	11/ 1/68	225/18°K Positive Gradient	None	Troubleshoot	
T73A	12/ 9/68	245/2°K Positive Gradient	F2	Acceptance	
T73B	12/11/68	225/18°K Positive Gradient	F2	Acceptance	
K17A(2A)	1/ 7/69	Evacuated Beads, 225°K	F2	Acceptance	

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THERMAL TEST SUMMARY (cont'd)

TEST NO.	DATE	TEST DESCRIPTION	ELECTRONICS	TEST TYPE	REMARKS
K17C(4B)	1/10/69	GN_2 Filled Beads, 225°K	F2	Acceptance	
K17E	1/16/69	Heater Tests	F2	Acceptance	
TC/F2	1/17/69	REF Junction and T.C. Test	F2	Acceptance	

NOTE:

The test type given by an acceptance in brackets indicates that the test was originally run as an acceptance test, but, because of system anomalies, the tests were rerun and are superseded by unbracketed acceptances.

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13 November 1967
15 December 1967 Rev. A
16 January 1968 Rev. B
2 February 1968 Rev. C
23 February 1968 Rev. D
10 April 1968 Rev. E
5 June 1968 Rev. F

TEST PROCEDURE NO. 0501

PART IV

THERMAL ENVIRONMENT TEST PROCEDURE

HEAT FLOW PROBE AND ELECTRONICS FOR ALSEP PROGRAM

MODEL: Flight 2

IDENTIFICATION

Probe Part No. 3709 F2-1

Probe Part No. 3709 F2-2

Electronics Box Part No. H937

Frank E. Ruccia
Arthur D. Little, Inc. Test Director

17 November 1967
Date

Richard J. DuVerneau
Arthur D. Little, Inc. Quality Assurance

17 November 1967
Date

This Revision has been approved by Bendix Aerospace Systems Division per their TWX No.S-1345 dated 24 June 1968

Arthur D. Little, Inc.

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REVISION SHEET

Revision	Date	Change
A	12/15/67	Additions: Table of Contents Section 3.0 through Section 5.0 pages 9 through 24
B	1/16/68	Applicable Document 1.3.15 Page 6 Paragraph 3.4.4.1.3 d Page 10 Paragraph 3.4.4.2.3 d Page 12 Paragraph 3.5.5 Page 14
C	2/2/68	Applicable Document 1.3.15 General Revisions - New Computer Program Paragraph 2.5.1 Page 6 Paragraph 2.5.3 Page 7 Paragraph 3.5.1 Page 13
D	2/23/68	Paragraph 3.5.2 Page 13 Cover Page to Applicable Document 1.3.15
E	4/10/68	Applicable Document 1.3.12 Pages 5,6 and 35
F	6/5/68	Title Page Pages 15, 25, 26 Applicable Documents 1.3.14, 1.3.16

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Rev. A: 15 Dec. 67

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HEAT FLOW PROBE PROGRAM

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Case 68647 ______

1.0 General

1.1 Purpose of Tests

To subject the heat flow probe to simulated thermal environments and measure the probe's response both with and without the electronics box.

1.2 Scope

This test procedure is applicable to the Heat Flow Probes and electronics box.

1.3 Applicable Documents

1.3.1	Electronics Box Data Package	
1.3.2	Rosemount Engineering Company Sensor Acceptance Tests and Calibration Results	
1.3.3	ΔT Apparatus Instrumentation - Block Diagram	3720-02
1.3.4	Probe Instrumentation - Block Diagram	3720-01
1.3.5	ΔT Apparatus - Flow Diagram	3722-001
1.3.6	K Apparatus - Flow Diagram	3723-001
1.3.7	Instrumentation Layout	3720-04
1.3.8	Instrument Room (Photo)	
1.3.9	Instrument Room (Photo)	
1.3.10	Temperature Gradient Apparatus (Photo)	
1.3.11	Thermal Conductivity Apparatus (Photo)	
1.3.12	Operation of Guildline Potentiometer, Instrument Nos. 300 and 364.	
1.3.13	Procedure for placement and removal of probe from temperature gradient and thermal conductivity apparatus.	
1.3.14	Electronics box and Bendix test set connections	
1.3.15	Data Analysis Procedures	
1.3.16	Instrument Calibration Expiration Dates	
1.3.17	Temperature Gradient Apparatus, Equipment and Parts List	
1.3.18	Thermal Conductivity Apparatus, Equipment and Parts List	
1.3.19	Bendix Heat Flow Equipment Test Set Preliminary Manual - Draft Copy - Prepared by C.S. Hocking, 15 December 1966. (Copy not included in these procedures.)	

1.3.20 Record of Acceptance Testing for Electronics Box Sensor Model 118YN and Thermocouple Cable, Appendix 1 of Rosemount Engineering Company Procedure No. 16627A.

1.3.21 Preliminary Specification Data for the Heat Flow Experiment Dual Static Probe, BxA AL 380200, Revision C. (Copy not included in these procedures.)

1.3.22 Deleted

1.3.23 Electronic Box Reference Junction Calibration Test Set-up.

1.4 Applicable Test Data Forms

1.4.1 Switch Coding Summary

1.4.2 Temperature Gradient Apparatus Data

1.4.3 Temperature Gradient Apparatus Data, Probe Bridge Data

1.4.4 Gradient Tube Controller Data

1.4.5 Thermal Conductivity Apparatus, Apparatus and Area Data

1.5 Participants Required

1.5.1 ADL Thermal Test Engineer

1.5.2 ADL technicians (two required)

1.5.3 ADL Quality Assurance

1.5.4 Bendix Quality Assurance Representative

1.5.5 DCAS Quality Assurance

1.6 Tests to be Performed (per probe basis)

1.6.1 Temperature Gradient Tests without Bendix Electronics (3 required)

1.6.2 Temperature Gradient Tests with Bendix Electronics (2 required)

1.6.3 Thermal conductivity tests with Electronics (2) required and Heater tests with electronics (2 required)

1.6.4 Electronic Box Temperature Bridge Test (1 required for both probes)

2.0 Temperature Gradient Test

2.1 Test Purpose

2.1.1 Functional test of probe

2.1.2 Determine bridge offsets

2.1.3 Determine shorting ratios for probe halves

2.1.4 Determine effective length of gradient bridge separation

2.2 Test Equipment--Temperature Gradient Apparatus
Applicable Documents: 1.3.3, 4, 5, 7, 8, 9, 10, and 17.

2.3 Test Required: Three tests are to be performed with each of two Heat Flow Probes as indicated.

Test No.	Nominal Temperature (°K)	Nominal Temperature Gradient (°K)	Gradient Direction [1]
1	205	2	Negative
2	225	0	N.A.
3	245	2	Positive

[1] A positive temperature gradient corresponds to the condition where the bottom part of the probe is warmer than the top part.

2.4 Test Procedure

The test articles consist of two Arthur D. Little, Inc. Heat Flow Probes. Procedure 2.4 is to be performed first with one probe and again with the second probe. Duration of test is not time limited.

2.4.1 Place one probe into the test apparatus gradient tube and connect probe leads to the terminals of the heat stationing block per Applicable Document 1.3.13.

2.4.2 Shut the vacuum closure of the test apparatus and activate the 2-inch diffusion and forepump vacuum system to evacuate the probe space to 2×10^{-5} mm Hg. or less.

2.4.3 Perform three Temperature Gradient tests.

2.4.3.1 Perform test with 2°K negative gradient

2.4.3.1.1 Adjust the power input to the apparatus tube heaters to produce a nominal tube temperature of 205°K ± 2.5°K (Switch 320-L) and a negative temperature gradient across each probe half of 2°K ± 0.25°K (Switch 300-D or 300-E). Allow time for the probe to reach temperature equilibrium with the gradient tube of the apparatus. This equilibrium is achieved when the variation in the gradient signal (Switch 300-D or 300-E) is less than 1.0 uv per hour. Record complete set of data on Data Form 1.4.4 and refer to Applicable Document 1.3.3 for switch location.

2.4.3.1.2 Obtain probe data using Guildline Potentiometer, Instrument No. 364. Use Applicable Documents and Forms 1.3.4, 1.3.12, 1.4.4, and 1.4.3 to record the following measured data.

Upper gradient bridge excitation voltage (Switch 369-2)
Upper gradient bridge excitation current (Switch 369-1-1)
Upper gradient bridge signal voltage (Switch 369-3)
Upper ring bridge excitation voltage (Switch 370-1)
Upper ring bridge excitation current (Switch 369-1-3)
Upper ring bridge signal voltage (Switch 370-2)
Lower gradient bridge excitation voltage (Switch 369-4)
Lower gradient bridge excitation current (Switch 369-1-2)
Lower gradient bridge signal voltage (Switch 369-5)
Lower ring bridge excitation voltage (Switch 370-3)
Lower ring bridge excitation current (Switch 369-1-4)
Lower ring bridge signal voltage (Switch 370-4)

2.4.3.1.3 Obtain gradient apparatus data using Guildline Potentiometer, Instrument No. 300. Use Applicable Documents and Forms 1.3.3, 1.3.12, and 1.4.2.

Measure and record upper gradient tube thermopile voltages (Switch 300-D) prior to and immediately following each group of measurements taken on the upper gradient bridge and on the upper ring bridge.

Measure and record lower gradient tube thermopile voltage (Switch 300-E) prior to and immediately following each group of measurements taken on the lower gradient bridge and on the lower ring bridge.

Measure and record the gradient tube temperatures on the L&N, K-3 potentiometer (Instrument No. 320) before and after the probe data is taken, using Data Form 1.4.2.

2.4.3.1.4 Obtain set of data for gradient apparatus and test area conditions on Data Form 1.4.4 prior to and following 2.4.3.1.2

2.4.3.2 Perform test with 0°K gradient

2.4.3.2.1 Adjust the power input to the apparatus tube heaters to produce a nominal tube temperature of 225°K $\pm$ 2.5°K (Switch 320-L) and a temperature gradient across each probe half of 0°K $\pm$ .1°K (Switch 300-D or 300-E). Allow time for the probe to reach temperature equilibrium with the gradient tube. This equilibrium is achieved when the variation in the gradient signal (Switch 300-D or 300-E) is less than 1.0 uv per hour.

2.4.3.2.2 Same as 2.4.3.1.2

2.4.3.2.3 Same as 2.4.3.1.3

2.4.3.2.4 Same as 2.4.3.1.4 Record complete set of data on Data Form 1.4.4

2.4.3.3 Perform test with 2°K positive gradient

2.4.3.3.1 Adjust the power input to the apparatus tube heaters to produce a nominal tube temperature of 245°K $\pm$ 2.5°K (Switch 320-L) and a positive temperature gradient across each probe half of 2°K $\pm$ 0.25°K (Switch 300-D or 300-E). Allow time for the probe to reach temperature equilibrium with the gradient tube of the apparatus. This equilibrium is achieved when the variation in the gradient signal (Switch 300-D or 300-E) is less than 1.0 uv per hours. Record complete set of data on Data Form 1.4.4 and refer to Applicable Document 1.3.3 for switch location.

2.4.3.3.2 Same as 2.4.3.1.2

2.4.3.3.3 Same as 2.4.3.1.3

2.4.3.3.4 Same as 2.4.3.1.4 Record complete set of data on Data Form 1.4.4.

2.4.4 Pressurize the probe space in the test apparatus to one atmosphere of pressure with gaseous nitrogen. Open the apparatus vacuum closure and disconnect the cable leads from the heat stationing block, and remove the probe from the apparatus. Seal gradient tube opening and evacuate gradient tube to a vacuum of less than 1000 microns.

2.5 Test Acceptance Criteria

Refer to Applicable Document 1.3.15, Data Analysis Procedures, for reduction of the test data.

2.5.1 Gradient Bridge Temperatures

The average temperature measured with each gradient bridge is to agree with the corresponding temperature of the gradient tube to within ± 0.15°K. The magnitude of this difference when averaged for all acceptance tests without electronics is to be within ± 0.10°K.

PROBE			GRADIENT APPARATUS	
No.	Half	Designation (1)	Thermocouple Designation	Temperature (1) Designation
1	Upper	TG11	320 J, K	TA01
1	Lower	TG12	320 M, N	TA02
2	Upper	TG21	320 J, K	TA01
2	Lower	TG22	320 M, N	TA02

(1) The first digit refers to the probe number and the second refers to upper and lower half of the probe (1 for upper and 2 for lower). Zero in the first digit refers to the gradient apparatus.

2.5.2 Gradient Bridge Differential Temperature

The differential temperature of each bridge is to be evaluated on the basis of a "shorting ratio", which is computed for each probe half using the following temperature data:

DTG = Differential temperature measured with the Gradient Bridge

DTA = Differential temperature measured with the Gradient Apparatus

TG = Temperature measured with Gradient Bridge

The shorting ratio is equal to DTG/DTA. The shorting ratio for each probe half during the test at 205°K ± 2.5°K (2.4.3.1) shall be greater than 0.92. The shorting ratios for the test at 245°K (2.4.3.3) shall be greater than 0.93.

The shorting ratio for each probe half is to be plotted as a function of absolute average temperature as measured by the gradient bridge, (TG), and a "best line" is to be drawn through the data. (Since the shorting ratio criteria is not used for measurements made with the probe in gradients less than 0.5°K, the "best line" may be determined by only two points.)

The slope of the "best line", $\frac{d\left(\frac{DTG}{DTA}\right)}{d\,(TG)}$ for each probe half shall be between 0.00015 and 0.00060 ($°K^{-1}$).

2.5.3 Ring Bridge Temperatures

The average temperature measured with each ring bridge is to agree with the corresponding temperature of the gradient tube to within ± .15°K after the bridge offset correction for lead removal is applied. The magnitude of this difference when averaged for all acceptance tests without electronics is to be within ± 0.10°K.

PROBE			GRADIENT APPARATUS	
No.	Half	Designation	Thermocouple Designation	Temperature Designation
1	Upper	TR11	320 J,K	TA01
1	Lower	TR12	320 M,N	TA02
2	Upper	TR21	320 J,K	TA01
2	Lower	TR22	320 M,N	TA02

2.5.4 Ring Bridge Differential Temperature

The differential temperature measured with the ring bridge is to be corrected for zero offset (2.5.5) resulting from lead wire removal during the probe assembly.

The corrected differential temperature of each ring bridge is to be evaluated on the basis of a "shorting ratio" which is computed for each probe half using the following data:

DTR = Corrected differential temperature measured with the ring bridge

DTA = Differential temperature measured with the gradient apparatus

TR = Corrected average absolute temperature measured with the ring bridge

The shorting ratio for the ring bridges is equal to DTR/DTA.

The shorting ratio for each ring bridge during the test at 205°K $\pm$ 2.5°K (2.4.3.1) shall be greater than 0.55.

The shorting ratios for the test at 245°K $\pm$ 2.5°K (2.4.3.3) shall be greater than 0.56. All shorting ratios shall be less than 0.61.

The shorting ratio for each probe half is to be plotted as a function of absolute average temperature as measured by the ring bridge (after the offset correction for lead removal is applied), and a "best line" is to be drawn through the data. (Since the shorting ratio criteria is not used for measurements made with the probe in gradients less than 0.5°K, the "best line" may be determined by only two points).

The slope of the "best line", $\frac{d\left(\frac{DTR}{DTA}\right)}{d\ (TR)}$, for each probe half ring bridge shall be between 0.00015 and 0.00060 (°K^{-1}).

2.5.5 <u>Gradient and Ring Bridge Differential Temperature Offsets</u>

The data obtained in accordance with 2.4.3.2 for the nominal 0°K gradient are to be used for computing the gradient and ring bridge differential temperature offsets.

The computed gradient bridge differential temperature is to exhibit less than $\pm$ .004°K zero shift following its initial calibration (REC) when the differential temperature is that imposed per Paragraph 2.4.3.2.1.

The computed ring bridge differential temperature is to exhibit less than ± 0.200°K total zero offset when the differential temperatures is that imposed per Paragraph 2.4.3.2.1.

3.0 Probe and Electronics Temperature Gradient Tests

3.1 Test Purpose

3.1.1 Functional Test of Probe-Electronics Sub-System

3.1.2 Measure probe temperature gradient and absolute temperature performance for comparison to those obtained without electronics at 2°K temperature gradient.

3.1.3 Measure probe temperature gradient and absolute temperature performance at 18°K temperature gradient.

3.2 Test Equipment

3.2.1 Temperature Gradient Apparatus, Applicable Document 1.3.3, 4, 5, 7, 8, 9, 10, and 17.

3.2.2 Bendix Electronic Test Set, Applicable Document 1.3.19.

3.3 Tests Required

Two tests are to be performed with each of two Heat Flow model probes as indicated.

Test No.	Nominal Temperature (°K)	Nominal Temperature Gradient (°K)	Gradient Direction
1	225	18	Positive
2	245	2	Positive

3.4 Test Procedure

The test article consits of two Arthur D. Little, Inc. probes connected to the Bendix Electronics. Procedure 3.4 is to be performed first with one probe and again with the second probe.

3.4.1 Place one probe into the test apparatus gradient tube and second probe into the storage tube provided in the apparatus.

3.4.2 Place Bendix Electronics into the test apparatus space provided on water cooled shelf. Connect the jumper cable from Bendix Electronics to the test apparatus feed through cable (See Applicable Document 1.3.14). Place the radiation shield over gradient tube opening.

3.4.3 Shut the vacuum closure on the test apparatus and activate the vacuum system to evacuate the probe-electronics space to less than 2×10^{-5} mm Hg. Utilize liquid nitrogen trap installed in temperature gradient apparatus 9-18-67 to maintain pressure below 2×10^{-5} mm Hg. with electronics outgassing.

3.4.4 Perform two temperature gradient tests. (The order of the 2° and 18° tests is not important.)

3.4.4.1 Perform test with 2°K gradient.

3.4.4.1.1 Adjust the electrical power input to the apparatus tube heaters to produce a nominal temperature of 245°K ± 2.5°K (Switch 320L) and a positive temperature gradient across each probe half of 2°K ± 0.25°K (Switch 300-D or 300-E). Allow time for the probe to reach temperature equilibrium with the gradient tube of the apparatus. This equilibrium is achieved when the variation in the apparatus gradient signal (Switch 300-D or 300-E) is less than 1.0 uv. Record one or more complete sets pretest information on Applicable Test Data Forms 1.4.2 and 1.4.4.

3.4.4.1.2 Obtain probe gradient bridge and probe thermocouple data. Give ETS commands C1, C4 and C5 to readout probe No. 1 data and commands C1, C4 and C6 to readout probe No. 2 data. Place ETS on printer readout and obtain 10 or more cycles of the following data.

a. Upper and lower half probe gradient probe bridge temperature data.

b. Upper and lower half probe gradient bridge differential temperature data in both the sensitive and insensitive modes.

c. Probe cable temperatures obtained from thermocouples.

d. Electronic box reference temperature.

All data sheets and ETS data tapes are to be appropriately identified and dated.

3.4.4.1.3 Measure and record the gradient apparatus data on applicable test data forms 1.4.2 and 1.4.4 immediately prior to and after the performance of 3.4.4.1.2 as follows:

a. Upper gradient tube thermopiles (switch 300 D)

b. Lower gradient tube thermopile (switch 300 E)

c. Gradient tube thermocouples (switch 320 J,K, M and N)

d. Gradient apparatus upper vacuum (Less than 2×10^{-5} mm Hg.)

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3.4.4.1.4 Obtain upper half probe ring bridge data in the following manner: Place ETS on binary display readout. Give ETS command C1 and set ETS on X16 frame rate. Give ETS command C10 and repeat this command as often as is necessary to obtain in 10 octal heater state when testing probe No. 1 and a 30 octal heater state when testing probe No. 2. Set ETS frame rate on X1. Give ETS commands C7 and C3 and confirm heater states on binary display. Place ETS on printer readout and obtain 10 or more cycles of the following data.

a. Upper half probe ring bridge temperature data.

b. Upper half probe ring bridge differential temperature data.

Appropriately identify and date all ETS data tapes.

3.4.4.1.5 Measure and record the gradient apparatus data on Applicable Test Data Forms 1.4.2 and 1.4.4 immediately prior to and after the performance of 3.4.4.1.4 as follows:

a. Upper gradient tube thermopile (switch 300 D)

b. Gradient tube thermocouples (switch 320 J, K, M and N)

c. Gradient apparatus upper vacuum. (Less than 2×10^{-5} mm Hg.)

3.4.4.1.6 Obtain lower half probe ring bridge data in the following manner: Place ETS on binary display readout. Give ETS command C1 and set ETS on X16 frame rate. Give ETS command C10 and repeat this command as often as is necessary to obtain a 14 octal heater state when testing probe No. 1 and a 34 octal heater state when testing probe No. 2. Set ETS frame rate on X1. Give ETS commands C7 and C3 and confirm heater state on binary display. Place ETS on printer readout and obtain 10 or more cycles of the following data:

a. Lower half probe ring bridge temperature data

b. Lower half probe ring bridge differential temperature data

Appropriately identify and date all ETS data tapes.

3.4.4.1.7 Measure and record the gradient apparatus data on applicable test data forms 1.4.2 and 1.4.4 immediately prior to and after the performance of 3.4.4.1.6 as follows:

a. Lower gradient tube thermopile (switch 300 E)

b. Gradient tube thermocouples (switch 320 J, K, M and N)

c. Gradient apparatus upper vacuum (Less than 2×10^{-5} mm Hg.)

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3.4.4.2 Perform test with 18°K gradient.

3.4.4.2.1 Adjust the electrical power input to the apparatus tube heaters to produce a nominal temperature of 225°K ± 2.5°K (Switch 320-L) and a positive temperature gradient across each probe half of 18°K ± 2°K (Switch 300-D or 300-E). Allow time for the probe to reach temperature equilibrium with the gradient tube of the apparatus. This equilibrium is achieved when the variation in the apparatus gradient signal (switch 300-D or 300-E) is less than 10 uv per hour. Record one or more complete sets of pretest information on applicable test data forms 1.4.2 and 1.4.4.

3.4.4.2.2 Obtain probe gradient bridge and probe thermocouple data. Give ETS commands C1, C4 and C5 to readout probe No. 1 data and commands C1, C4 and C6 to readout probe No. 2 data. Place ETS on printer readout and obtain 10 or more cycles of the following data:

a. Upper and lower half probe gradient probe bridge temperature data.

b. Upper and lower half probe gradient bridge differential temperature data in both the sensitive and insensitive modes.

c. Probe cable temperatures obtained from thermocouples.

d. Electronic box reference temperature.

All data sheets and ETS data tapes are to be appropriately identified and dated.

3.4.4.2.3 Measure and record the gradient apparatus data on applicable test data forms 1.4.2 and 1.4.4 immediately prior to and after the performance of 3.4.4.2.2 as follows:

a. Upper gradient tube thermopiles (switch 300 D)

b. Lower gradient tube thermopile (switch 300 E)

c. Gradient tube thermocouples (switch 320 J,K, M and N)

d. Gradient apparatus upper vacuum (Less than 2×10^{-5} mm Hg.)

3.5 Test Acceptance Criteria

Refer to Applicable Document 1.3.15, Data Analysis Procedures, for the reduction of the test data and Applicable Document 1.3.1 for Electronic box errors.

3.5.1 Gradient Bridge Temperature

The average temperature measured with each gradient bridge for the 2°K gradient is to agree with the corresponding temperature of the test apparatus gradient tube within $\pm$ 0.15°K plus the standard deviation in degrees of the error due to the electronic box. (Applicable Document 1.3.1)

For the 18°K gradient, the absolute average temperature measured be the lower gradient bridge is to be decreased by an offset of 0.2°K. The upper gradient bridge temperature, and the corrected lower gradient bridge temperature are to agree with the corresponding temperature of the test apparatus within $\pm$ .15°K plus the standard deviation in degrees of the error due to the electronic box (Applicable Document 1.3.1)

3.5.2 Gradient Bridge Differential Temperature

The differential temperature obtained with each gradient bridge is to be evaluated on the basis of the shorting rates defined in paragraph 2.5.2 of this procedure.

Following the acceptance tests with electronics, the "best line" through the shorting ratios is to be recomputed. Since the tests without electronics are inherently more accurate than those which include the additional error due to the electronics, the shorting ratios from tests without electronics are to be weighted twice in recomputing the "best line". The "best line" calculation is described in Section 2.5.2 . The recomputed "best line" shall meet the requirements with respect to minimum shorting ratio at 205°K and 245°K and with respect to slope, as specified in Section 2.5.2.

The shorting ratio for each half probe obtained in the test at 245°K (3.4.4.1) shall be within $\pm$ 0.0025 of the recomputed "best line" shorting ratio (equivalent to $\pm$ 0.005°K).

The shorting ratio for each half probe obtained in the test at 225°K (3.4.4.2) shall be within $\pm$ 0.0025 of the recomputed "best line" shorting ratio (equivalent to $\pm$ 0.050°K).

3.5.3 Ring Bridge Temperatures

The average temperature measured with each ring bridge is to agree with the corresponding temperature of the test apparatus gradient tube within $\pm$ 0.15°K plus the standard deviation in degrees of the error due to the electronic box. (Applicable Document 1.3.1)

3.5.4 Ring Bridge Differential Temperature

The corrected differential temperature obtained with each ring bridge is to be evaluated on the basis of the shorting ratio defined in paragraph 2.5.4

Following the test with electronics at 245°K, the "best line" through the shorting ratios is to be recomputed. The tests without electronics are weighted twice in the computation, for the reasons described in Section 3.5.2.

The recomputed "best line" shall meet the requirements for maximum and minimum shorting ratio values and for "best line" slope as specified in Section 2.5.4.

The shorting ratios for each half probe obtained in the test at 245°K (3.4.4.1) shall be within ± .01 of the recomputed "best line" shorting ratio (equivalent to $\pm$ 0.010°K).

3.5.5 Cable Thermocouple

The probe data obtained in accordance with 3.4.4.1.2 c and d is to be reduced using the ADL furnished thermocouple and electronic box temperature sensor calibration data (Applicable Document 1.3.20). The data from thermocouple nearest the probe is the only data requiring resolution.

The computed thermocouple temperature is to meet the following criteria:

$$TC = TG - \frac{DTG}{2} \pm [0.5°K + \text{Electronics Box Errors}]$$

where TC = thermocouple temperature

TG = temperature of upper probe half

DTG = differential temperature measured with upper probe half

4.0 Probe and Electronics Thermal Conductivity Tests

4.1 Test Purpose

4.1.1 Calibrate probes and electronics at low thermal conductivity.

4.1.2 Calibrate probes and electronics at high thermal conductivity.

4.2 Test Equipment

4.2.1 Thermal conductivity apparatus consisting of Chambers No. 1 and No. 2. Applicable Documents 1.3.6, 1.3.18, and 1.3.11.

4.2.2 Bendix Electronic test set. Applicable Document 1.3.19

4.3 Test Required

Probe	Probe Half	Heater	Heater Power (Watts)	Conductivity Material[1]	Nominal Conductivity Material Temperature (°K)
1	Upper	2	.002	Evacuated Beads	225
2	Lower	4	.002	Evacuated Beads	225
1	Lower	4	.500	GN_2 Filled Beads	225
2	Upper	2	.500	GN_2 Filled Beads	225

(1) Refer to Thermal Conductivity Determination for "K" Apparatus Test Material Over the 200°K to 250°K Operating Range - Dated 6/3/68

4.4 Test Procedure

The test article consists of two Arthur D. Little, Inc. probes connected to a Bendix Electronics Box.

4.4.1 Probe and Electronics Test Preparation

4.4.1.1. Place Bendix Electronics on water-cooled shelf of Apparatus Chamber No. 1. Insert probe No. 1 into the bore tube provided in the thermal conductivity material placed in Chamber No. 1. Insert probe No. 2 into the bore tube provided in the thermal conductivity material placed in Chamber No. 2. Connect the jumper cable from the Bendix Electronics to the test apparatus feedthrough cable (refer to Applicable Document 1.3.14).

4.4.1.2 Shut the vacuum chamber opening on the test apparatus and activate the vacuum systems to each chamber to evacuate the probe electronics space to less than 5×10^{-5} mm Hg. Refer to Applicable Document 1.3.6.

4.4.1.3 The set temperature of thermal conductivity material is to be in the range of 220 to 235°K and is to be maintained at $\pm$ .5°K throughout the test.

4.4.2 Perform four thermal conductivity tests as indicated in 4.3.

4.4.2.1 Perform calibration test of probe No. 1 in conductivity Apparatus No. 1 at low thermal conductivity.

4.4.2.1.1 Evacuate the thermal conductivity material in Apparatus No. 1 using the bead tank vacuum pumping system item 207.

4.4.2.1.2 Read and record one set of data on Applicable Form 1.4.5 for Conductivity Apparatus No. 1. The measured chamber vacuum shall be 5×10^{-5} mm Hg. or less and the bead pressure shall be 20 microns of pressure or less.

4.4.2.1.3 Place ETS on lights readout and ETS cycle rate on X16. Then, select heater H12 in the off state by giving ETS command C1 and repeating command C10 as often as required to step heater bits to an octal reading of 00. Return ETS cycle rate to X1.

4.4.2.1.4 Place probe 1 in the probe select measuring mode by giving ETS commands C1, C4 and C5 in the order given and set ETS in printer readout. Observe line 2 of Number 0 data block (I.D. bits are 00 in octal). When the variation in the data of line 2 is less than 6 bits per hour proceed to the next step.

4.4.2.1.5 Begin the thermal conductivity test by giving the ETS commands C1, C10, and C2.

4.4.2.1.6 Observe printer readout and certify that mode identification is given by 10 octal and heater identification is given by 02 octal. The low-K mode differential temperature and absolute temperature are given by 00 and 10 octal respectively on the P bits (first line of I.D. information). Identify, date and time on tape at hourly intervals until test is terminated.

4.4.2.1.7 Repeat 4.4.2.1.2 after start of test and at hourly intervals until the test is terminated. The exact timing of these data intervals is not critical to the test.

4.4.2.1.8 The duration of the test from start to finish is approximately 24 hours. Observe line 2 of the No. 0 data block (P bits have a 00 octal value). Terminate test when the variation in the data of line 2 is 6 bits or less per hour. The test is terminated when command C1 is given to the ETS.

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4.4.2.1.9 After termination of test fill thermal conductivity material of Apparatus No. 1 with vaporized liquid nitrogen to atmospheric pressure.

4.4.2.2 Perform calibration test of probe No. 2 in conductivity Apparatus No. 2 at low thermal conductivity.

4.4.2.2.1 Evacuate the thermal conductivity material in Apparatus No. 2 using the bead tank vacuum pumping system item 207.

4.4.2.2.2 Read and record one set of data on Applicable Form 1.4.5 for Conductivity Apparatus No. 2. The measured chamber vacuum shall be 5×10^{-5} mm Hg. or less and the bead pressure shall be 20 microns of pressure or less.

4.4.2.2.3 Place ETS on lights readout and ETS cycle rate on X16. Then, select heater H24 in the off state by giving ETS command C1 and repeating command C10 as often as required to step heater bits to an octal reading of 24. Return ETS cycle rate to X1.

4.4.2.2.4 Place probe 2 in the probe select measuring mode by giving ETS commands C1, C4 and C6 in the order given and set ETS in printer readout. Observe line 2 of the Number 3 data block (I.D. bits are 03 in octal). When the variation in the data of line 2 is less than 6 bits per hour proceed to the next step.

4.4.2.2.5 Begin the thermal conductivity test by giving the ETS commands C1, C10 and C2.

4.4.2.2.6 Observe printer readout and certify that mode identification is given by 10 octal and heater identification is given by 26 octal. The low-K mode differential temperature and absolute temperature are given by 03 and 13 octal respectively on the P bits (first line of I.D. information). Identify, date and time on tape at hourly intervals until test is terminated.

4.4.2.2.7 Repeat 4.4.2.2.2 after start of test and at hourly intervals until the test is terminated. The exact timing of these data intervals is not critical to the test.

4.4.2.2.8 The duration of the test from start to finish is approximately 24 hours. Observe line 2 of the No. 3 data block

(P bits have a 03 octal value). Terminate test when the variation in the data of line 2 is 6 bits or less per hour. The test is terminated when command C1 is given to the ETS.

4.4.2.2.9 After termination of test fill thermal conductivity material of Apparatus No. 2 with vaporized liquid nitrogen to atmospheric pressure.

4.4.2.3 Perform calibration test of probe No. 1 in Apparatus No. 1 at high thermal conductivity.

4.4.2.3.1 The thermal conductivity material of Apparatus No. 1 is filled with vaporized liquid nitrogen to atmospheric pressure per 4.4.2.1.9. Allow approximately 20 hours for the temperature field of the thermal conductivity material to stabilize. After completion of test performed in 4.4.2.2 proceed to next step.

4.4.2.3.2 Read and record one set of data on applicable form 1.4.5 for conductivity Apparatus No. 1. The measured chamber vacuum shall be 5×10^{-5} mm Hg. or less and the bead pressure shall be 0 ± 5 inches Hg. gage.

4.4.2.3.3 Place ETS on lights readout and ETS cycle rate on X16. Then select heater H14 in the off state by giving command C1 and repeating command C10 as often as required to step heater bits to an octal reading of 04 (3rd line of the I.D. information). Return ETS cycle rate to X1.

4.4.2.3.4 Place probe 1 in probe select measuring mode by giving ETS commands C1, C4, and C5 in the order given and set ETS in printer readout. Observe line 2 of the number 1 data block (I.D. bits are 01 in octal). When the variation in the data of line 2 is less than 6 bits per hour, proceed to the next step.

4.4.2.3.5 Begin the thermal conductivity by giving the ETS commands C1, C10, C7 and C3.

4.4.2.3.6 Observe printer readout and certify that mode identification is given by 04 octal and the heater identification is given by 06 octal. The high K mode differential temperature and absolute temperature are given by 00 and 01 octal respectively on the P bits (first line I.D. information). Identify, date and time tape at hourly intervals until test is terminated.

4.4.2.3.7 Repeat 4.4.2.3.2 after start of test and at hourly intervals until the test is terminated. The exact timing of these data is not critical to the test.

4.4.2.3.8 The duration of the test from start to finish is 6 hours. At plus six hours of test time terminate test by giving ETS command C1.

4.4.2.4 Perform calibration test of probe No. 2 in Apparatus No. 2 at high thermal conductivity.

4.4.2.4.1 The thermal conductivity material of Apparatus No. 2 is filled with vaporized liquid nitrogen to atmospheric pressure per 4.4.2.2.9. Allow approximately 20 hours for the temperature field of the thermal conductivity material to stabilize. After completion of test performed in 4.4.2.3 proceed to next step.

4.4.2.4.2 Read and record one set of data on Applicable Form 1.4.5 for conductivity Apparatus No. 2. The measured chamber vacuum shall be 5×10^{-5} mm Hg. or less and the bead pressure shall be 0 ± 5 inches Hg. gage.

4.4.2.4.3 Place ETS on lights readout and ETS cycle rate on X16. Then select heater H22 in the off state by giving command C1 and repeating command C10 as often as required to step heater bits to an octal reading of 20 (3rd line of the I.D. information). Return ETS cycle rate to X1.

4.4.2.4.4 Place probe 2 in probe select measuring mode by giving ETS commands C1, C4, and C6 in the order given and set ETS in printer readout. Observe line 2 of number 2 data block (I.D. bits are 02 in octal). When the variation in the data of line 2 is less than 6 bits per hour proceed to the next step.

4.4.2.4.5 Begin the thermal conductivity by giving the ETS commands C1, C10, C7 and C3.

4.4.2.4.6 Observe printer readout and certify that mode identification is given by 04 octal and the heater identification is given by 22 octal. The high K mode differential temperature and absolute temperature are given by 02 and 03 octal respectively on the P bits (first line I.D. information). Identify, date and time tape at hourly intervals until test is terminated.

4.4.2.4.7 Repeat 4.4.2.4.2 after start of test and at hourly intervals until the test is terminated. The exact timing of these data is not critical to the test.

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4.4.2.4.8 The duration of the test from start to finish is 6 hours. At plus six hours of test time terminate test by giving ETS command C1.

4.4.3 Test the functional performance of heaters 1 and 3 on each probe.

4.4.3.1 The conductivity materials of Apparatus No. 1 and Apparatus No. 2 are at a pressure of one atmosphere of gaseous nitrogen per 4.4.2.1.9 and 4.4.2.2.9. The probe space pressure can have any value up to 760 mm Hg.

4.4.3.2 Check the temperature stability of probe No. 1. Place probe in the select mode by giving ETS commands C1, C4 and C5. Set ETS in printer readout. When the bridge signal given by the 2nd line in data blocks 0 and 1 (I.D. P bits 00 and 01 respectively) have a variation less than 500 octal per hour proceed to the next step.

4.4.3.3 Place ETS on lights readout and ETS cycle rate on X16. Place heater No. 1 on probe No. 1 in the on-state by giving ETS command C1 and repeating command C10 as often as required to step heater bits to an octal reading of 12. Return ETS cycle rate of X1 and return ETS to printer readout.

4.4.3.4 Obtain 6 or more cycles of the upper half-probe gradient bridge data by giving ETS commands C1, C4,C5 and C7.

4.4.3.5 Immediately following one of the data printouts obtained in 4.4.3.4, give ETS command C3 which energizes heater No. 1 at the 0.5 watt level.

4.4.3.6 Immediately following the first data printout obtained in 4.4.3.5 give ETS command C1 to de-energize heater No. 1.

4.4.3.7 Obtain 6 or more cycles of upper half-probe gradient data. No additional ETS commands are required.

4.4.3.8 Place ETS on lights readout and ETS cycle rate on X16. Place heater No. 3 on probe No. 1 in the on-state by giving ETS command C1 and repeating command C10 as often as required to step heater bits to an octal reading 16. Return ETS cycle rate to X1 and ETS readout to printer.

4.4.3.9 Obtain 6 or more cycles of lower half-probe gradient bridge data by giving ETS commands C1, C4, C5 and C7.

4.4.3.10 Immediately following one of the data printouts obtained in 4.4.3.9, give ETS command C3 which energizes heater No. 3 at the 0.5 level.

4.4.3.11 Immediately following the first data printout obtained in 4.4.3.10 give ETS command C1 to de-energize heater No. 3.

4.4.3.12 Obtain 6 or more cycles of lower half-probe gradient data. No additional ETS commands are required.

4.4.3.13 Check the temperature stability of probe No. 2. Place probe in the select mode by giving the ETS commands C1, C4 and C6. Set ETS in printer readout. When the bridge signal given by 2nd line in data blocks 2 and 3 (I.D. P bits 02 and 03 respectively) have a variation less than 500 octal per hour proceed to the next step.

4.4.3.14 Place ETS on lights readout and ETS cycle rate on X16. Place heater No. 1 on probe No. 2 in the on-state by giving ETS command C1 and repeating command C10 as often as required to step heater bits to an octal reading of 32. Return ETS cycle rate to X1 and ETS readout to printer.

4.4.3.15 Obtain 6 or more cycles of the upper half-probe gradient bridge data by giving ETS commands C1, C4, C6 and C7.

4.4.3.16 Immediately following one of the data printouts obtained in 4.4.3.15, give ETS command C3 which energizes heater No. 1 at the 0.5 watt level.

4.4.3.17 Immediately after the first printout obtained in 4.4.3.16 give ETS command C1 to de-energize heater No. 1.

4.4.3.18 Obtain 6 or more cycles of upper half-probe gradient data. No additional ETS commands are required.

4.4.3.19 Place ETS on lights readout and ETS cycle rate on X16. Place heater No. 3 on probe No. 2 in the on-state by giving ETS command C1 and repeating command C10 as often as required to step heater bits to an octal reading 36. Return ETS cycle rate to X1 and ETS readout to printer.

4.4.3.20 Obtain 6 or more cycles of lower half-probe gradient bridge data by giving ETS commands C1, C4,C6 and 7.

4.4.3.21 Immediately following one of the data printouts obtained in 4.4.3.20, give ETS command C3 which energizes heater No. 3 at the 0.5 watt level.

4.4.3.22 Immediately after the first printout obtained in 4.4.3.21, give ETS command C1 to de-energize heater No. 3.

4.4.3.23 Obtain 6 or more cycles of lower half-probe gradient data. No additional ETS commands are required.

4.4.3.24 Date and identify all tapes.

4.4.4 Remove probes and electronics from thermal conductivity apparatus.

4.4.4.1 Isolate the vacuum system to the chamber of each apparatus by closing valves V252 and V254.

4.4.4.2 Pressurize the chamber of each apparatus to atmospheric pressure with vaporized liquid nitrogen.

4.4.4.3 Initiate gaseous nitrogen purge at each chamber.

4.4.4.4 Lift and rotate chamber vacuum doors.

4.4.4.5 Disconnect electronics box from ETS apparatus feed-through cable.

4.4.4.6 Remove probes and electronics box from the conductivity apparatuses.

4.4.4.7 Rotate and shut chamber vacuum doors.

4.4.4.8 Evacuate thermal conductivity apparatus chamber.

4.5 <u>Acceptance Criteria</u> (See Applicable Document 1.3.15 for data analysis procedures)

4.5.1 Probe performance at a thermal conductivity of 7.7×10^{-5} watt/cm °K (low thermal conductivity).

The data obtained for the active probe half in accordance with 4.4.2.1 and 4.4.2.2 are to be reduced using the REC gradient bridge calibration data, and BxA electronic box calibration factor. The gradient bridge differential temperature are to be computed for each data point.

The curve of the gradient bridge differential temperature as a function of time is to have the following characteristics:

a. Shape of curve to be similar to that obtained with Engineering Model Probe No. 2 tests K3B through K3F.

b. The curve shall have a rise of 0.2 to 0.50°K at a heater power level of .002 watts.

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4.5.2 Probe performance at a thermal conductivity of 1.8×10^{-3} watt/cm°K (high thermal conductivity).

The data obtained for the active probe half in accordance with 4.4.2.3 and 4.4.2.4 are to be reduced using REC ring bridge calibration data including offset corrections and BxA electronic box calibration factor. The curve, representing rate of change of the ring bridge differential temperature as a function of time, $\Delta(\Delta T)/\Delta\theta$, is to have an average slope of 0.0016 ± 0.0005°K/min at 300 minutes from the beginning of the test.

4.5.3 Performance of Probe Heaters

When heater No. 1 and 3 on each probe are momentarily energized, the corresponding gradient bridge signal, five minutes after heater actuation, will have an octal value that is smaller than the value prior to heater actuation by a minimum of 2000 octal.

5.0 Electronic Box Temperature Bridge and Cable Thermocouple Tests

5.1 Test Purpose

Establish performance of electronics box temperature bridge and cable thermocouples.

5.2 Equipment

5.2.1 BxA ETS (Applicable Document 1.3.19)

5.2.2 Potentiometer (L & N K-3) and calibrated thermocouple ($\pm$ .1°K accurancy).

5.3 Test Required

One test required in which the temperature of the electronics mounting plate is measured at the vicinity of the temperature bridge.

5.4 Test Procedure

5.4.1 Thermally bond calibrated thermocouple junction to the electronics box and prepare measuring system for reading out thermocouple voltage (See Applicable Document 1.3.23).

5.4.2 Place probe and electronic box on test bench in room environment. Connect jumper cable to BxA ETS and electronics box. Insulate outside of electronic box mounting plate with insulating foam board. Place probes into 12 ft. long double barrel isothermal tubes. Allow at least one hour for probes and isothermal tube to become temperature equilibrated.

5.4.3 Give ETS commands Cl, C4, C5 C8 and C9 to printout probe No. 1 cable thermocouple data and electronic box reference junction data. Obtain temperature data for a period of one hour.

5.4.4 Give ETS commands Cl, C4, C6, C8 and C9 to printout probe No. 2 cable thermocouple data and electronics box reference junction data. Obtain temperature data for a period of one hour.

5.4.5 Simultaneous with 5.4.3 and 5.4.4 read calibrated thermocouple voltage at about 2-minute intervals.

5.4.6 Terminate test by giving ETS commands Cl and turn off power to electronics.

5.5 Acceptance Criteria

Thermocouple voltage measurements are to be reduced using AVCO thermocouple calibration data.

ETS printout data for electronic box temperature bridge is to be reduced using REC bridge calibration data (Applicable Document 1.3.20) and BxA electronic box calibration factors (Applicable Document 1.3.1).

The temperatures obtained for both the calibrated thermocouple and electronics box bridge are to be graphed on the same time base. Agreement between the two shall be within $\pm$ [0.5°K + Electronic Box Errors]

Thermocouples No. 2, 3 and 4 on each cable are to show a maximum differential temperature of $\pm$ [0.5°K + Electronic Box Errors]

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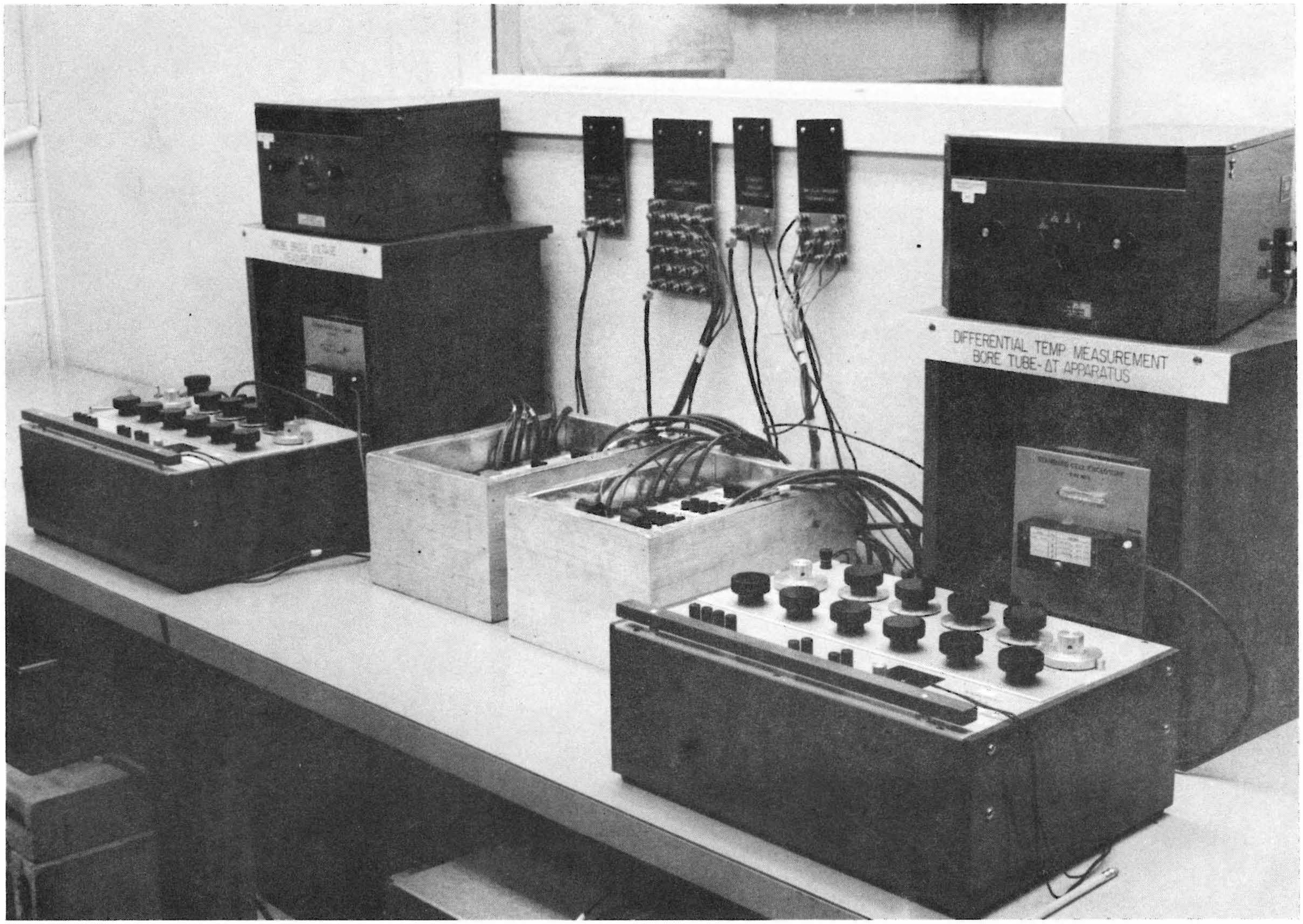
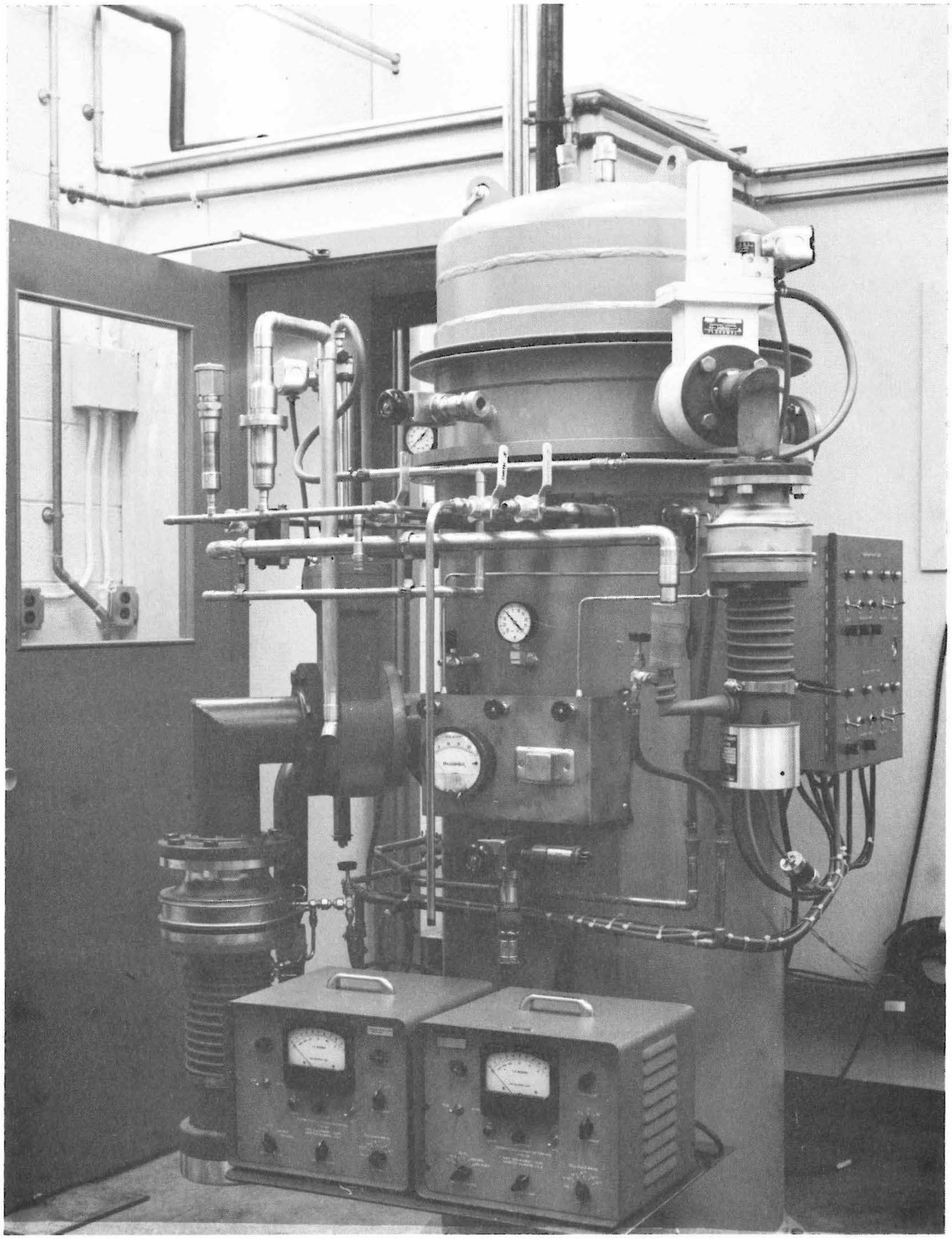
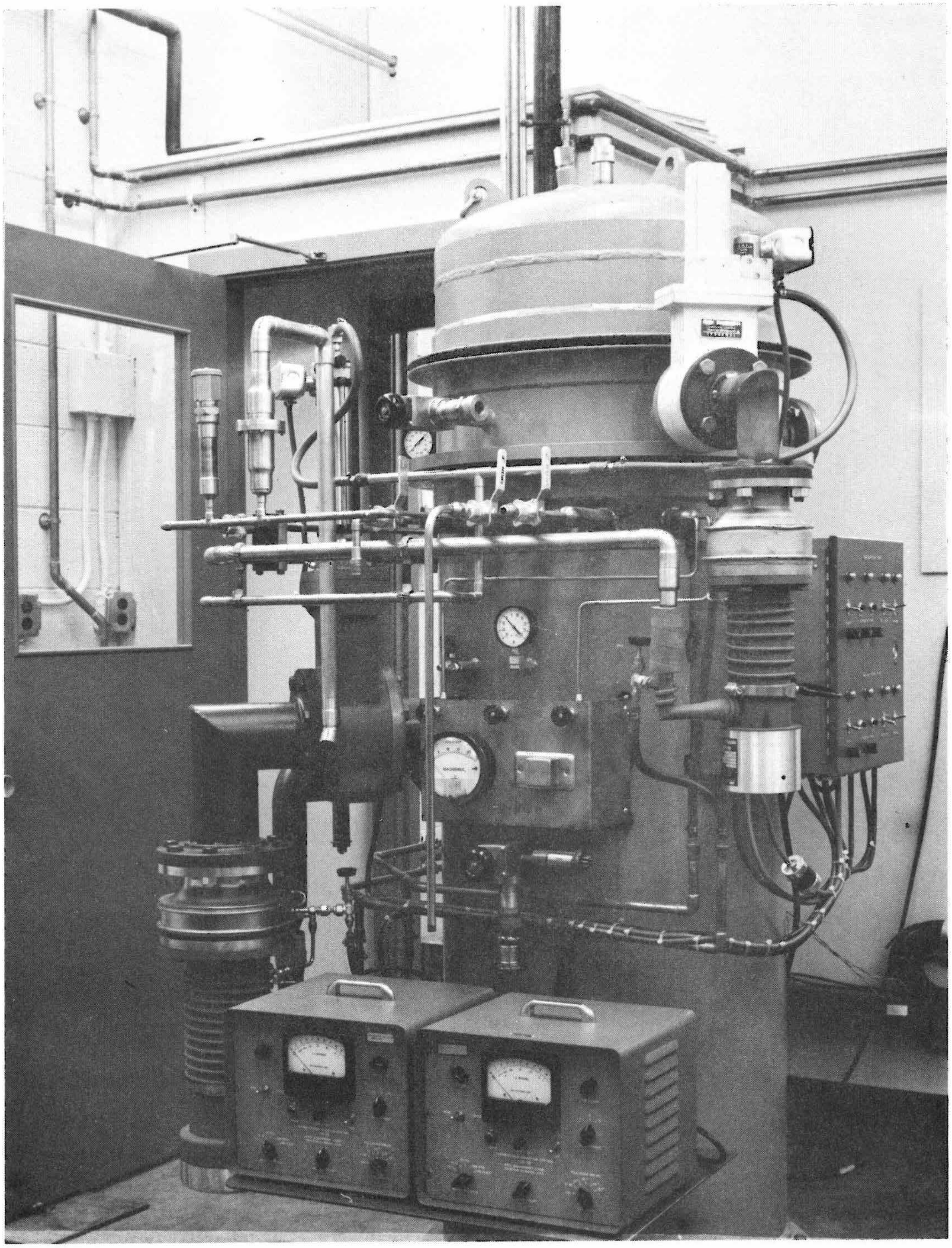


Applicable Document 1.3.8 Instrument Room

Applicable Document 1.3.9 Instrument Room



Applicable Document 1.3.10 Temperature Gradient Apparatus



Applicable Document 1.3.10 Temperature Gradient Apparatus

HEAT FLOW PROBE PROGRAM

Bendix Contract SC 0242

Case 68647 -5

Applicable Document - 1.3.12

Date: 29 March 1967
Rev.: 14 June 1967

OPERATION OF GUILDLINE POTENTIOMETER INSTRUMENT NOS. 300 and 364

1. Release all "Sensitivity" buttons on potentiometer.

2. Set Amplifier Zero at Galvanometer Sensitivity "1/10"

   a. Always zero the amplifier with its input open. Release either all "Sensitivity" buttons or both "Galvanometer Reverse" buttons or both "Standardize" and "Measure" buttons. This is the correct procedure for the amplifier connected for series feedback and adjusted to low gain.

   b. The zero is determined by the mechanical constraints of the amplifier galvanometer, and it shows hysteresis after large overloads. Therefore, always operate the secondary galvanometer at high sensitivity (1/10) and attenuate, if required, at the potentiometer rather than at the galvanometer. This procedure keeps the signal level at them amplifier input down.

   c. The zero will drift appreciably in normal operation, and galvanometer reversal must always be used to ascertain balance during measurement.

   d. The "Zero" positions of the Guildline switches external to the potentiometer do not short the potentiometer input, but rather replace the respective signal source by an equivalent resistor.

3. Standardize Galvanometer

To standardize, place "Sensitivity" buttons in nonlocking position (white dots horizontal), press "Standardize" and "Galvanometer +" buttons and set galvanometer sensitivity at 1/10. Begin balance by momentarily pressing potentiometer sensitivity button #1 and balance to within 10 uv. <u>Attention</u>: <u>NEVER</u> begin with buttons 2, 3, 4. <u>NEVER</u> press both galvanometer + and - buttons simultaneously. These mistakes could damage the standard cell by drawing excessive current from it.

Standardize galvanometer prior to any temperature gradient tests. Check standardization several times during progress of test.

4. <u>Check Amplifier Zero</u>

Release "Standardize" button and proceed as in Step 2 above.

5. <u>Measure Input Voltage with Potentiometer</u>

Set polarity and range to the expected values on the potentiometer dials, if the value is known. Set the potentiometer measuring dials to about ten percent below the expected value and then proceed to Step No. 8. However, if the value of the signal and its polarity is not known, the following bracketing technique should be used:

a. Set the potentiometer range dial to .01, the signal polarity to (+) and all measuring dials to zero. Depress the "Meas" and "Galv +" button on the potentiometer. Then, depress momentarily the "Galv No. 1" button and note the direction of the deflection on the galvanometer.

b. Set the potentiometer measuring dials to 100000 value and the signal polarity dial to (+). <u>Momentarily</u> depress "Galv No. 1" button and again note the direction of the galvanometer deflection.

If deflection in "b" is in the direction opposite to that obtained in "a", the signal has a value between 0 and 100000 with range dial set at .01.

If, on the other hand, the two deflections are in the same direction, then position the signal polarity switch on (-) and again depress "Galv No. 1" button.

If the direction of the deflection is opposite to that obtained in "a", the signal is between 0 and -100000 with range dial set on .01.

If the direction of the deflection is still the same as that obtained in "a", proceed to the next step.

NOTE

Extreme caution should be used in depressing sensitivity buttons. They should be used only in the momentary contact position (dots parallel to long direction of nanopot case) until value is well bracketed.

c. Repeat Step 5.b. with increasing values on dials and range until deflection direction changes. At some point before this occurs, there will be a noticeable difference in the galvanometer reponse between the plus trial value and the minus trial value. At this point, one should discontinue trial values with polarities that indicate gross signal vs. pot differences, i.e., very rapid galvanometer movement.

d. When a deflection direction change is noted, decrease the dial setting by one. Increase the next lower decade dial setting until a deflection direction change is noted at this level. Reduce this value by one and continue this process down to the extreme right side. At the lower values, switch noise will be quite noticeable. True zero can only be obtained by reversing galvanometer and noting deflection values with buttons locked down and hands off the pot. When using this technique, disregard Steps 6, 7, and 8.

6. Press "Measure" button, and, with sensitivity buttons in the nonlocking position, press #1 button momentarily. Note direction of galvanometer deflection.

7. Try progressively increasing values on the "0.01" dial until deflection direction changes. Then reduce this value by one.

8. Repeat Step 7 at each decreasing decade until number of significant figures desired is obtained.

9. Always use galvanometer reversal to avoid false zero in final balance.

10. Note polarity, range and all dial settings, including zeroes, on the appropriate data forms.

11. Reduce galvanometer sensitivity to 1/1000 and release all buttons on the potentiometer.

HEAT FLOW PROBE PROGRAM

Bendix Contract SC 0242

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Applicable Document - 1.3.13

Date: 15 June 1967
Rev.:

PROCEDURE FOR PLACEMENT AND REMOVAL OF PROBE FROM TEMPERATURE GRADIENT AND THERMAL CONDUCTIVITY APPARATUS

1. Carefully remove outcoming probe from bore tube and place into storage hole.
2. Place bore tube evacuation plug assembly into top of tube and evacuate bore tube.
3. Remove machine screws from circular junction cover and remove cover.
4. Remove aluminum foil tape holding cable in heat stationing grooves.
5. Loosen binding posts on circular junction plate and carefully remove probe cables from posts.
6. Coil probe cable and carefully take the probe and cable out of the apparatus.
7. Very carefully insert incoming probe into storage hole.
8. Separate probe cable wires for easy identification.
9. Upper and lower probe cables are identified by cable number. (Refer to Rosemount's cable identification sheet for correct number for a particular probe.) For each probe half the gradient and ring bridges are banded white and black respectively.
10. Firmly attach each individual wire to its proper binding post according to the schedule in Table I.
11. Recheck binding post for proper probe wire connection.
12. Coil one loop of each cable in the heat stationing grooves of the circular junction box and tape down with aluminum foil tape.
13. Install circular junction cover with machine screws.

14. Connect potentiometer to probe bridge and check out leads at Switch 399, after making sure #364 nanopot is out of the circuit (all buttons released).

15. Apply voltage to upper gradient bridge with probe bridge power supply position #1 in the positive mode.

16. Depress switch #369-3 and read out on potentiometer. (This is primarily a polarity and continuity check. It is not possible to check polarity of the signal leads unless there is a known gradient in the probe.)

17. Repeat Steps 15 and 16 for the other three bridges using power supply and read out switches as identified on "switch coding summary" sheet. Correct any mistakes before proceeding.

18. Bleed dry N_2 gas into bore tube and remove plug assembly from the top of the bore tube.

19. Take the probe out of the storage hole and carefully lower it into the bore tube until it bottoms on the probe stop.

20. With the probe emplacement tool push the small radiation shield down to the top of the probe.

21. Place the large radiation shield around the probe cable and slide it down to the top of the bore tube.

22. Remove any extraneous equipment from the top vacuum chamber and replace cover. Evacuate the chamber with the auxiliary 5 C.F.M. vacuum pump over a period of 10 minutes. When top chamber pressure is less than 29" high, the 4" high vacuum valve may be opened.

NOTE

Steps 18 through 22 should be completed as rapidly as possible because of the thermal pertibation introduced by the warm high pressure gas.

23. If there are no apparent leaks then the probe change is completed.

NOTE

The thermal conductivity apparatus does not have nor does it require a probe storage hole. When applying the above procedure to the thermal conductivity apparatus, the bore tube of the apparatus is used as the storage hole.

TABLE I

PROBE CABLE CONNECTIONS TO CIRCULAR JUNCTION PLATE

TEMPERATURE GRADIENT AND THERMAL CONDUCTIVITY APPARATUSES

Upper Probe Cable Identification			Apparatus Junction Plate Marking	
Bridge & Color Band	No. or Color	Polarity	Letter	Position
Gradient Bridge and White Band	Red	plus	P_1	Outer Terminal
	Brown	minus	P_1	Inner "
	Yellow	plus	V_1	Outer "
	Green	minus	V_1	Inner "
	Blue	plus	S_1	Outer "
	White	minus	S_1	Inner "
Ring Bridge and Black Band	Red	plus	P_3	Outer "
	Brown	minus	P_3	Inner "
	Yellow	plus	V_3	Outer "
	Green	minus	V_3	Inner "
	Blue	plus	S_3	Outer "
	White	minus	S_3	Inner "
Heater Connections	H_1		H_1	
	H_2		H_2	
	H_3		H_{12}	

Lower Probe Cable Identification			Circular Junction Plate Marking	
Bridge & Color Band	No. or Color	Polarity	Letter	Position
Gradient Bridge and White Band	Red	plus	P_2	Outer Terminal
	Brown	minus	P_2	Inner "
	Yellow	plus	V_2	Outer "
	Green	minus	V_2	Inner "
	Blue	plus	S_2	Outer "
	White	minus	S_2	Inner "

TABLE I (Contd)

Lower Probe Cable Identification			Circular Junction Plate Marking	
Bridge & Color Band	No. or Color	Polarity	Letter	Position
Ring Bridge and Black Band	Red	plus	P_4	Outer Terminal
	Brown	minus	P_4	Inner "
	Yellow	plus	V_4	Outer "
	Green	minus	V_4	Inner "
	Blue	plus	S_4	Outer "
	White	minus	S_4	Inner "
	H_1		H_3	
	H_2		H_4	
	H_3		H_{34}	

HEAT FLOW PROBE PROGRAM

Applicable Document 1.3.14 of
Test Procedure 0501, Part IV

Bendix Contract SC 0242
Case 68647 -5

Date: 16 June 1967

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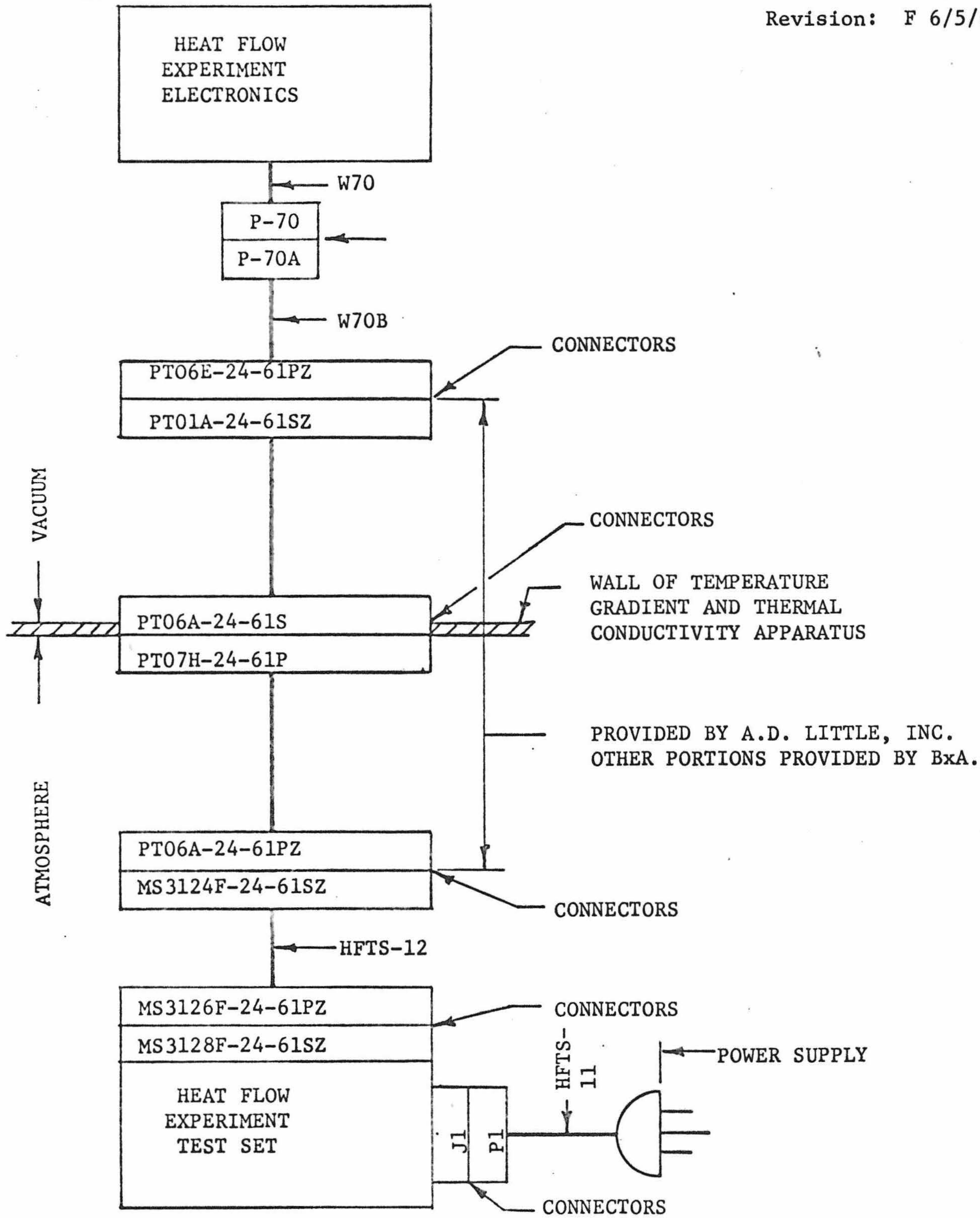


CABLE CONNECTION DIAGRAM
HEAT FLOW EXPERIMENT, ADL TEST APPARATUS,
HEAT FLOW EXPERIMENT TEST SET

Arthur D. Little, Inc.

HEAT FLOW PROBE PROGRAM

Bendix Contract SC 0242

Case 68647 ______

AS APPLIED TO TEST PROCEDURE 0501

PART IV, REVISION C, D, and E

APPLICABLE DOCUMENT NO. 1.3.15

DATA ANALYSIS PROCEDURES

Rev. C:2/2/68
Rev. D:2/23/68
Rev. E:4/10/68

TABLE OF CONTENTS

1.0 Introduction

Data reduction and analysis procedures are described for heat flow probe test programs conducted at Arthur D. Little, Inc. The data reduction procedure depends on previous calibrations conducted on a component level and the data analysis procedure provides additional information required for interpretation of heat flow probe assembly data. Sections 3-6 present the methods used for interpreting ADL test data; Section 7 gives a description of recommended procedures for subsequent heat flow probe data reduction. Refer to Test Procedure No. 0501, Part II, for the Thermal Environment Test Procedure for the Heat Flow Probe.

2.0 Nomenclature

2.1 Temperature

ΔT Apparatus

TA01	Absolute average temperature - upper
TA02	Absolute average temperature - lower
DTA01	Temperature difference - upper
DTA02	Temperature difference - lower

Probe Gradient Bridges

TG11	Absolute average temperature - Probe 1 - upper
TG12	Absolute average temperature - Probe 1 - lower
TG21	Absolute average temperature - Probe 2 - upper
TG22	Absolute average temperature - Probe 2 - lower
DTG11	Differential temperature, gradient sensor, high sensitivity, Probe No. 1, upper half
DTG12	Differential temperature, gradient sensor, high sensitivity, Probe No. 1, lower half
DTG21	Differential temperature, gradient sensor, high sensitivity, Probe No. 2, upper half
DTG22	Differential temperature, gradient sensor, high sensitivity, Probe No. 2, lower half
DTGL11	Differential temperature, gradient sensor, low sensitivity, Probe No. 1, upper half
DTGL12	Differential temperature, gradient sensor, low sensitivity, Probe No. 1, lower half

DTGL21 Differential temperature, gradient sensor, low sensitivity, Probe No. 2, upper half

DTGL22 Differential temperature, gradient sensor, low sensitivity, Probe No. 2, lower half

Probe Ring Bridges

TR11 Absolute average temperature - Probe No. 1 - upper

TR12 Absolute average temperature - Probe No. 1 - lower

TR21 Absolute average temperature - Probe No. 2 - upper

TR22 Absolute average temperature - Probe No. 2 - lower

DTR11 Differential temperature, ring sensor - Probe No. 1 - upper

DTR12 Differential temperature, ring sensor - Probe No. 1 - lower

DTR21 Differential temperature, ring sensor - Probe No. 2 - upper

DTR22 Differential temperature, ring sensor - Probe No. 2 - lower

Reference Junction Bridge

TCR Absolute average temperature of reference junction

Thermocouples

TC11 Temperature difference between lowest junction (at uppermost gradient sensor) and reference junction - Probe 1

TC12 Temperature difference between lowest and top thermocouple junctions - Probe 1

TC13 Temperature difference between lowest and second highest thermocouple junctions - Probe 1

TC14 Temperature difference between lowest and second lowest thermocouple junctions - Probe 1

TC21-24 Same as above for Probe 2

2.2 Length

LA Centerline-to-centerline spacing of thermopiles on ΔT Apparatus gradient tube (corrected to 225°K) (= 18.684 in.)

LG Centerline-to-centerline spacing of probe gradient sensors (225°K)

LR Centerline-to-centerline spacing of probe ring sensors (225°K)

3.0 Reduction of "ΔT Apparatus" Test Data

3.1 "ΔT Apparatus" Instrumentation

3.1.1 Absolute Average Temperature (TA)

Four reference thermocouples are located along the gradient tube in the "ΔT Apparatus". The locations correspond to the centerline positions of the gradient sensors. Therefore, an arithmetic average of the upper two thermocouple temperatures corresponds approximately to the average temperature indicated by the upper gradient bridge; and similarly, the lower two thermocouples, to the lower gradient bridge.

The thermocouples were calibrated individually by Avco Corporation. The four copper-constantan thermocouples were found to have the same calibration. Section 8.2 gives the actual values of thermocouple temperature and EMF at 0.1°C intervals over the operating temperature ranges (the calibration accuracy is < ± 0.1°K).

Average gradient tube temperature is found by converting measured EMF's into temperatures using the Avco Corporation tabulations and linear interpolation. The arithmetic average temperature is found for upper and lower locations and converted to °K by addition of 273.159 to the average temperature in °C. Including instrumentation, the error band on absolute temperature is ± .13°K.

3.1.2 Differential Temperature (DTA)

Measuring thermopiles are also located across the upper and lower probe half locations. These are ten-junction chromel-constantan assemblies which were calibrated by Rosemount Engineering Company at eight data points. The EMF versus temperature data for both the gradient tube thermopiles can be obtained by applying a linear correction fact~r of 10.046 to the standard chromel-constantan data tabulation (ORNL 3649, Vol. 2). The calibration error for the thermopiles is ± .0012°K; with errors for readout included, the thermopile accuracy is ± .002°K.

3.2 Probe Data (Without Electronics)

3.2.1 Gradient Sensors (TG, DTG)

Bridge output voltage (E_o) is measured for known excitation voltages (E_i) of both positive and negative polarity.[1] The effect of thermal EMF's can be eliminated by using

$$\frac{E_o}{E_i} = \frac{E_o^+ - E_o^-}{E_i^+ - E_i^-}$$

where the superscripts represent the polarity of the excitation pulse.

Bridge resistance (R_B) is also measured by monitoring the voltage drop across a precision resistor in the bridge circuit so that bridge current may be calculated. Again polarity is reversed and excitation voltages are also measured.

Probe Sensor Bridge Data Reduction Procedure

Required Input

R_B, E_o/E_i

Basic Model

Let $Y_1 = R_B$

$Y_2 = R_B \dfrac{E_o}{E_i}$

$X_1 = t$ °C [= T1 in REC nomenclature
= temperature of lower sensor]

$X_2 = \Delta t$ °C

[1] Applicable Document 1.4.3 of Test Procedure No. 0501, Part II.

REC Equations

$$Y_1 = C_1 + C_2X_1 + C_3X_1^2 + C_4(X_1 - 100)X_1^3 + C_5X_2 + C_6X_2(2X_1 + X_2)$$

$$Y_2 = C_7 + C_8X_1 + C_9X_1^2 + C_{10}X_2 + C_{11}X_2(2X_1 + X_2) + C_{12}\left\{X_2(4X_1^3 - 300X_1^2) + X_2^2(6X_1^2 - 300X_1) + X_2^3(4X_1 - 100) + X_2^4\right\}$$

C_1 through C_{12} are calibration constants furnished by Rosemount Engineering Company for each bridge (see applicable document 1.3.2 of Test Procedure 0501, Part II).

<u>Iterative Technique for Solving for t and Δt, given R_B, E_o/E_i and Bridge Calibration Constants</u>

a. Let $Y_1 = R_B$ experimental value

$Y_2 = R_B \frac{E_o}{E_i}$ experimental value

and let Y_{1n} = nth estimate of Y_1 using REC equation

Y_{2n} = nth estimate of Y_2 using REC equation

b. Let $F_{1n} = Y_{1n} - Y_1$

$F_{2n} = Y_{2n} - Y_2$

c. Then $$\frac{\partial F_{1n}}{\partial X_{1n}} = C_2 + 2C_3X_{1n} + C_4(4X_{1n}^3 - 300X_{1n}^2) + 2C_6X_{2n}$$

$$\frac{\partial F_{1n}}{\partial X_{2n}} = C_5 + 2C_6(X_{1n} + X_{2n})$$

Rev. E:10 April 68

$$\frac{\partial F_{2n}}{\partial X_{1n}} = C_8 + 2C_9X_{1n} + 2C_{11}X_{2n}$$

$$+ C_{12}\left\{12X_{2n}X_{1n}^2 + 12X_{2n}^2X_{1n} - 600X_{1n}X_{2n} - 300X_{2n}^2 + 4X_{2n}^3\right\}$$

$$\frac{\partial F_{2n}}{\partial X_{2n}} = C_{10} + 2C_{11}(X_{1n} + X_{2n}) + C_{12}\left\{4X_{1n}^3 - 300X_{1n}^2\right.$$

$$\left. + 12X_{2n}X_{1n}^2 - 600X_{1n}X_{2n} + 12X_{1n}X_{2n}^2 - 300X_{2n}^2 + 4X_{2n}^3\right\}$$

d. Let $DET = \frac{\partial F_{1n}}{\partial X_{1n}} \frac{\partial F_{2n}}{\partial X_{2n}} - \frac{\partial F_{2n}}{\partial X_{1n}} \frac{\partial F_{1n}}{\partial X_{2n}}$

e. Iterative Procedure

i. Set $n = o$

ii. Assume initial values

$X_{10} = (Y_1 - 502.5)/1.99$

$X_{20} = Y_2$

iii. Compute

$$\text{Error 1} = \left\{\frac{\partial F_{2n}}{\partial X_{2n}} F_{1n} - \frac{\partial F_{1n}}{\partial X_{2n}} F_{2n}\right\} /DET$$

$$\text{Error 2} = \left\{\frac{\partial F_{2n}}{\partial X_{1n}} F_{1n} + \frac{\partial F_{1n}}{\partial X_{1n}} F_{2n}\right\} /DET$$

iv. Compare

Is $|\text{Error 1}| < .01$?

Is $|\text{Error 2}| < .0001$?

<u>If not</u>, let $n = n + 1$

$X_{1n} = X_{1n} - \text{Error 1}$

$X_{2n} = X_{2n} - \text{Error 2}$

and return to step iii.

<u>If so</u>, computation is complete and

$X_1 = X_{1n} = t\ °C$

$X_2 = X_{2n} = \Delta t\ °C$

v. Finally, convert to °K and find bridge average temperature

$$T_{AVG} = 273.159 + X_1 + \frac{1}{2}X_2 \quad °K \quad (TG)$$

$$\Delta T = X_2 \quad °K \quad (DTG)$$

The computer program used to solve these equations is listed in Section 8.3.

3.2.2 Ring Sensors

3.2.2.1 Absolute Average Temperature (TR)

Following calibration at Rosemount Engineering Company, the interconnecting leads on the ring bridge are shortened by about 20 cm. The removal of this wire results in a nominal decrease of 0.8Ω in bridge resistance or a nominal error of 0.4°K in absolute temperature measurement, relative to the original calibration. In reducing Arthur D. Little, Inc. test data, measured ring bridge resistance is increased by the approximate value of 0.8Ω. The procedure described in 3.2.1 is then used to obtain TR and DTR using measured values: E_o^+, E_o^-, E_1^+, E_1^- and $(R_B + 0.8)$.

Subsequently, an additional absolute temperature offset is found by finding the mean value of the experimentally determined quantity, (TR - TA). Then, since the temperature coefficient of resistance is about 1.99Ω/°K

$$\text{TR offset} = -0.4 + (TR - TA)_{mean} \quad °K$$

$$\text{or} \quad \Delta R_B = -0.8 + 1.99\,(TR - TA)_{mean} \quad \Omega$$

The temperatures listed on the Arthur D. Little, Inc. data summary sheets (see Section 8.1.2) for TR (Column 5) have been corrected for the offset (ΔR_B in equivalent ΔT °K) shown on the performance criteria sheet (see Section 8.1.4).

3.2.2.2 Temperature Difference (DTR)

The removal of interconnecting lead wire may also introduce a zero offset in the DTR measurement. This offset is determined from data obatined in tests with near zero temperature differential across the bridge. These tests are tabulated at the bottom of the test data summary sheet (Section 8.1.2). The mean value of the offset and standard deviation from the mean are presented on the performance criteria sheet. (Section 8.1.4)

Actual ring bridge temperature difference for "non-zero" gradient tests is found by subtracting the offset from the value of DTR found using the normal Rosemount Egnineering Company data reduction procedure. Values of DTR (Column 8, Test Data Summary, Section 8.1.2) have been corrected for zero offset.

3.3 Probe Data (With Electronics)

3.3.1 Gradient Sensors (TG, DTG)

When tests are conducted using probe electronics, the data reduction procedures to convert electronics output signals to R_B and E_o/E_i involve several calibration factors and data reduction procedures provided by Bendix Aerospace Systems Division. For each gradient bridge, two such factors are needed for DTG measurement, one more for DTGL measurement, and another for TG measurement. In addition, the total resistance of the bridge excitation leads must also be known. (This value is provided as calibration data by Rosemount Engineering Company.) Calibration constants are summarized on the "Calibration Constant" data summary sheet in the form shown in Section 8.1.1. TG and DTG may then be found using the procedures of Section 3.2.1.

3.3.2 Ring Sensors (TR, DTR)

For each ring bridge, two electronics calibration constants are needed for DTR and one more for TR measurements. Lead resistance is also required. The ring sensors do not have a low sensitivity mode of operation.

In ring bridge measurements, the value of R_B is to be corrected by the ΔR_B offset factor before proceeding with data reduction, following the procedures given in Section 3.2.2.

3.3.3 Reference Junction (TCR)

The reference junction sensor is also a bridge, but has only two elements with resistance which varies with temperature. There is an electronics calibration constant associated with finding E_o/E_i for the reference junction.

The reference junction sensor measures absolute temperature of the reference junction block located in the probe electronics box. A Rosemount Engineering Company calibration at five temperatures (-20, 0, 25, 50, 90°C) is used to determine the constants in the following equation:

$$\frac{E_o}{E_i} = K_1 + K_2(TCR) + K_3(TCR)^2 + K_4(TCR)^3$$

Subsequently TCR can be found using the calibration constants and E_o/E_i data.

3.3.4 Thermocouples (TC)

The eight thermocouples (four in each probe cable) in a probe assembly are initially calibrated by Rosemount Engineering Company at 90°, 200°, 250° and 350°K with their reference junctions maintained at 0°C. The four data points for each thermocouple are used to define three ranges (90° to 200°K, 200°K to 250°K, and 250°K to 350°K) and to find a linear correction factor to apply to a standard chromel-constantan data tabulation (ORNL 3649, Vol. 2) within each range.

Data reduction requires use of an equation involving three constants to convert electronics box output to a thermocouple EMF. Then, the measured EMF is scaled by the linear correction factor which applies to the particular thermocouple in the particular range of absolute temperature operation to obtain and equivalent standard differential EMF. The procedure begins with the known reference junction temperature (TCR) obtained from the procedure in 3.3.3. Then the standard EMF's for TC11 or TC21 may be added to the standard EMF at (TCR) to determine the standard EMF of the lower junction in probe 1 or probe 2 respectively. The corresponding absolute temperature of the lowest thermocouple junction in each probe may then be found by linear interpolation in the standard tables.

The absolute temperature at the lowest thermocouple position (at the location of the uppermost probe gradient sensor) is then used as a reference level for the other three thermocouples. The EMF's indicated after application of the electronics data reduction procedures represent differences between the lowest thermocouple and the highest (TC12 or TC22), second highest (TC13 or TC23), and third highest (TC14 or TC24) thermocouples respectively.

The detailed steps are as follows:

3.3.4.1 Find standard EMF at TCR.

3.3.4.2 Add measured EMF to standard EMF at reference junction temperature. This corresponds to the "real" EMF of the thermocouple.

3.3.4.3 Estimate an approximate temperature using the "real" EMF and standard tables.

3.3.4.4 Calculate the difference between "real" and standard EMF's at the approximate temperature from the equation developed from Rosemount Engineering Company calibration data.

$$\text{DELE} = [E_{real} - E_{std}] = \begin{cases} C_1 + C_2\ (T-350) & 250 \text{ to } 350°K \\ C_1 + C_2\ (250-350) + C_3\ (T-250) & 200 \text{ to } 250°K \\ C_1 + C_2\ (250-350) + C_3\ (200-250) + C_4\ (T-200) & 90 \text{ to } 200°K \end{cases}$$

3.3.4.5 Calculate E_{std} (1st approximation) for thermocouple.

$$E_{std} = E_{real} - \text{DELE}$$

3.3.4.6 Find corresponding temperature in standard tables. Use this temperature and repeat steps 3.3.4.4. to 3.3.4.6 until two successive approximations differ by less than 0.01°K. This is then the temperature for the junction.

3.3.4.7 Since upper themocouples are referenced to the bottom thermocouple junction, the "real" EMF for TC12, TC13 and TC14 (or 22, 23 and 24) is found by subtracting the measured EMF from E_{real} for TC11 (or 21).

3.3.4.8 Repeat steps 3.3.4.4 through 3.3.4.6 to find corresponding temperatures.

4.0 Interpretation of ΔT Apparatus Test Data

4.1 Gradient Sensors

4.1.1 Absolute Average Temperature

Absolute average temperature measurements made with the probe are compared to those indicated by the corresponding gradient apparatus tube instrumentation. The values should agree within the accuracy of the respective measurements at temperatures across the probe of 2°K or less.

However, additional error is introduced for nominal 20° temperature differential tests. This is due to the fact that the probe is radiatively coupled to the gradient tube. Although the gradient tube temperature distribution is essentially linear, at high ΔT's the radiation resistance varies from the hot to the cold end of the probe and introduces a non-linear distribution in the probe. Therefore, absolute temperature measurements tend to be less accurate in a 20° gradient than in gradients of 2° and below across a probe half.

The difference between absolute average temperature measured by temperature gradient apparatus instrumentation and the corresponding probe gradient bridge is tabulated in Column 6 on the test data summary sheets (Section 8.1.2). The standard deviation of these differences is used as a performance criteria for absolute temperature measurement. This value is presented on the "performance criteria" summary sheet for each bridge.

4.1.2 Differential Temperature

4.1.2.1 "Best Line" Analysis

Since the heat flow probe acts as a parallel thermal path to the gradient tube and since it is radiatively coupled to the gradient tube, the probe sensors detect a temperature differential which is less than that across corresponding points in the gradient tube. The ratio of probe ΔT to gradient tube ΔT (across a corresponding distance has been referred to as the "shorting ratio").

The shorting ratio for each test data point is tabulated in Column 9 on the test data summary sheets (Section 8.1.2). Because of the radiative coupling effects, this ratio is a function of temperature.

The test data for all tests, except those run at near-zero temperature difference, are used to determine the equation of a "best line", in a least mean square error sense, through values of this ratio versus absolute temperature.

$$\frac{DTG}{DTA} = K_1 + K_2 \, TG$$

Then the deviation from the "best line" is found in terms of a temperature difference (Column 10). The predicted value of DTG = DTA $[K_1 + K_2 \, TG]$

$$\text{Deviation} = (DTG)\ \text{Experimental} - (DTG)\ \text{Predicated}$$
$$= (DTG)\ \text{Experimental} - (DTA)\ [K_1 + K_2\ (TG)]$$

Deviations are tabulated for all "non-zero" tests.

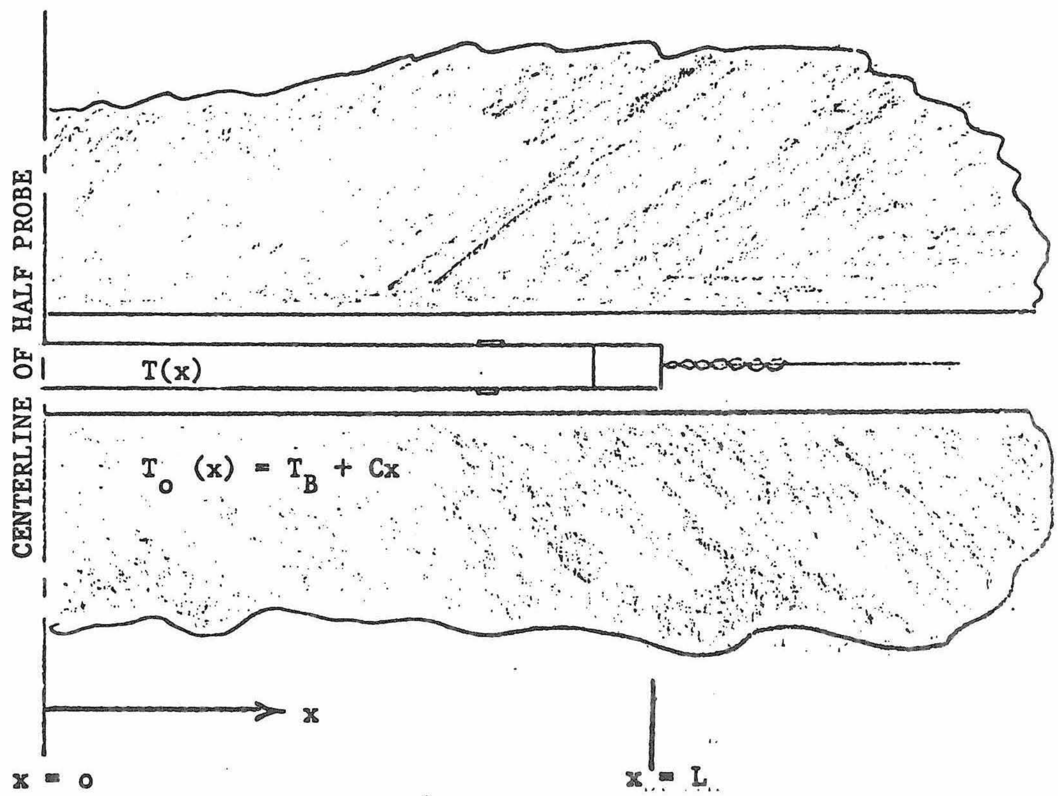
The standard deviation of data points from this line (in °K) is used as one performance criterion. "Zero ΔT" tests and "20° ΔT" tests are not included in the standard deviation calculation. Therefore, this figure represents an error band on nominally "2° ΔT" probe bridge measurements.

4.1.2.2 Effective Length Analysis

FIN EFFECTIVENESS MODEL FOR HEAT FLOW PROBE

1. Derivation

The model developed for interpreting the "dc" shorting performance of the heat flow probe assumes that the probe is a cylindrical fin of known size and conductance. The fin is inserted into a concentric surrounding material which is separated from the fin by a radiation gap. A linear temperature distribution in the axial direction exists in the surroundings. By assuming that the system is symmetrical about the midpoint of a half probe, the model shown in Figure 1 is obtained.



$T(o) = T_o(o) = T_B$

FIGURE 1

FIN MODEL FOR HEAT FLOW PROBE

"DC" SHORTING ANALYSIS

Therefore if $X = 0$ is the midpoint of a probe half and L is the distance from the midpoint to the end of the probe half, the temperature distribution in the probe can be found as $T(x)$, for an imposed surrounding temperature field described by $T_o(x) = T_B + Cx$, where C is the constant temperature gradient in the surroundings.

For the present heat flow probe design:

Probe half thermal resistance = (Calculated from design drawings) $\begin{cases} 10{,}950\ ^\circ\text{K/watt upper} \\ 14{,}240\ ^\circ\text{K/watt lower} \end{cases}$

Probe effective conductance/unit length $\quad kA = \dfrac{2L}{R_p} \quad \dfrac{\text{watts cm}}{^\circ\text{K}}$ (1)

Heat transfer to surroundings is described by a heat transfer coefficient, h, which includes radiative transfer and conduction into surroundings. For analysis of ΔT apparatus results, the value of h is determined by radiation resistance only:

$$\text{Per unit length:} \quad h\pi D = 4\sigma\varepsilon T^3 \pi D \equiv \frac{1}{2LR_R} \tag{2}$$

where R_R = total radiation resistance around probe

$$\text{let } m^2 = \frac{\pi Dh}{KA} = \frac{1}{2LR_R} \frac{R_P}{2L} = \frac{1}{L^2} \left[\frac{R_P}{4R_R} \right] \tag{3}$$

$$\text{and } \Theta = T - T_B \tag{4}$$

$$\text{Equation:} \quad \frac{\partial^2\theta}{\partial x^2} - m^2\Theta = -m^2 Cx \tag{5}$$

$$\text{Homogeneous soln:} \quad \Theta_h = C_1 e^{mx} + C_2 e^{-mx} \tag{6}$$

$$\text{Particular soln:} \quad \Theta_p = C_3 x + C_4 \tag{7}$$

Substituting $\Theta = \Theta_h + \Theta_p$ in original equation:

$$-m^2 (C_3 x + C_4) = -m^2 Cx \tag{8}$$

$$\therefore \quad C_3 = C \qquad C_4 = 0 \tag{9}$$

Boundary conditions:

(1) at x = 0 $\quad T(o) = T_B$ or $\theta = o$ (10)

(2) at X = L, assume that heat loss from end of probe is characterized by an effective heat transfer coefficient, h_e. Then

$$\left.\frac{\partial\theta}{\partial x}\right|_{x = L} = \frac{-h_e}{k}\,[\theta - CL] \tag{11}$$

From condition 1:

$$C_1 + C_2 = 0 \qquad \text{or} \qquad C_2 = -C_1 \tag{12}$$

$$\theta = C_1\,(e^{mx} - e^{-mx}) + CX \tag{13}$$

From condition 2:

$$-\frac{h_e}{k}\,[C_1(e^{mL} - e^{-mL})] = C_1 m\,(e^{mL} + e^{-mL}) + C \tag{14}$$

$$\text{or}\quad C_1 = -\frac{C}{m}\left[\frac{1}{(e^{mL} + e^{-mL}) + \frac{h_e}{mk}(e^{mL} - e^{-mL})}\right] \tag{15}$$

Therefore,

$$\theta = C\left\{\frac{1}{m}\,\frac{(e^{-mx} - e^{mx})}{(e^{mL} + e^{-mL}) + \frac{h_e}{mk}(e^{mL} - e^{-mL})} + X\right\} \tag{16}$$

Simplifying for mx and mL >> 1

$$\frac{\theta}{CX} = 1 - \frac{1}{mx}\,\frac{e^{mx}}{e^{mL}(1 + \frac{h_e}{mk})} = 1 - \frac{1}{mx}\,\frac{e^{-mL\,(1 - \frac{X}{L})}}{(1 + \frac{h_e}{mk})} \tag{17}$$

or finally,

$$\frac{\theta}{CL} = \frac{X}{L} - \frac{1}{mL}\,\frac{E^{-mL(1 - \frac{X}{L})}}{(1 + \frac{h_e}{mk})} \tag{18}$$

2. Application to ΔT Apparatus Tests

Relating this to the ΔT apparatus measurements, we observe

$$\Theta = \frac{\Delta T}{2} \text{ probe gradient sensors} \tag{19}$$

$$C = \frac{\Delta T}{2(LA)} \text{ thermopiles on gradient tube} \tag{20}$$

where 2(LA) = centerline spacing of thermopiles

$$\frac{\Delta T_{probe}}{\Delta T_{thermopiles}} \quad \frac{(LA)}{L} = \frac{X}{L} - \frac{1}{mL} \; \frac{e^{-mL\,(1 - \frac{X}{L})}}{(1 + \frac{h_e}{mk})} \tag{21}$$

A further assumption is needed to assign a value to h_e, the end heat transfer coefficient. A reasonable approximation is to set the value of h_e equal to the equivalent coefficient for the sides of the probe.

$$\text{Then,} \quad h_e = h_R = \frac{1}{2\pi D L R_R} \quad \text{(Eq. 2)} \tag{22}$$

$$k = \frac{2L}{R_P} \frac{4}{\pi D^2}$$

$$\frac{h_e}{mk} = \frac{mD}{4} = (mL)\,\frac{D}{4L} \tag{23}$$

The final form used in interpreting data is:

$$\frac{\Delta T_{probe}}{\Delta T_{thermopiles}} \quad \frac{(LA)}{L} = \frac{X}{L} - \frac{1}{mL} \; \frac{e^{-mL\,(1 - \frac{X}{L})}}{[1 + mL\,(\frac{D}{4L})]} \tag{24}$$

$$\text{with } mL = \left[\frac{R_P}{4\,R_R}\right]^{1/2} \tag{25}$$

$$R_P = \begin{cases} 14{,}240 \text{ lower half} & {}^\circ\text{K/watt} \\ 10{,}950 \text{ upper half} & \end{cases} \tag{26}$$

$$R_R = [4\sigma\epsilon T^3 \pi D 2L]^{-1} \tag{27}$$

$\sigma = 5.67 \times 10^{-12}$ watts/cm^2 °K^4

$\varepsilon = 0.9$

T = average probe half temperature (test data) °K

D = .75" average probe diameter or 1.9 cm

2L = probe half length - measured for each probe half ≈ 53 cm. (corrected to 225°K - from room T - .040" thermal contraction)

2(LA) = centerline spacing between thermopiles (corrected to 225°K) ≈ 18.68" or 48.2 cm

ΔT_{probe} = measured temperature difference across probe bridge (test data)

$\Delta T_{thermopiles}$ = measured gradient tube temperature difference between thermopiles (test data)

Test data and dimensions are substituted in eq. 24 and used to solve by trial and error for X. "Effective probe length" = 2X.

If 2y or LG = centerline gradient sensor spacing, then the measuring point on the sensor can is displaced toward the center of the probe by (y - x).

Since a major thermal connection between the probe body and the sensor element at each probe half end is an epoxy bond at the end of the can toward the middle of the probe section, the effective measuring point should lie in a band between the epoxy joint and the centerline on each sensor element.

Since the distance between the sensor centerline and epoxy joint is 0.7" for a typical sensor,

$$0 < (y-x) < 0.7''$$

Analysis of test data will permit narrower limits to be assigned.

The values being computed for each data point $(TG, \frac{DTG}{DTA})$ on each half probe are:

y - x = displacement of measuring point inward from sensor centerline

2X = effective length of probe

$\frac{2X}{LG}$ = ratio of probe effective length to centerline spacing of gradient sensors.

The ratio $\frac{2X}{LG}$ is used as the performance criterion for probe bridge temperature gradient measurement.

4.2 Ring Sensors

4.2.1 Offset Determinations

As described in Section 3.2.2.1, the lead wires in the ring sensor bridge are shortened by about 20 cm. following the original bridge calibration at Rosemount Engineering Company. This results in an offset in bridge resistance (affecting absolute temperature determination) and may introduce a "zero shift" in bridge output signal (affecting temperature difference determination). Both these offsets are determined in the course of testing in the ADL differential temperature apparatus.

4.2.1.1 Absolute Average Temperature

Since the bridge resistance is decreased by a nominal value of 0.8Ω due to lead wire removal, test data for ring sensors is originally reduced by adding 0.8Ω to the measured value of bridge resistance, and using the data reduction procedure of Section 3.2.1. The absolute average temperatures so calculated are compared with the ΔT Apparatus absolute average temperatures, by tabulating the differences between corresponding pairs of values. The mean value of the differences is then taken for all tests in the series and this is assumed to be the additional offset. For example, if all the temperatures measured by a particular ring bridge turned out to be 0.1°K lower than the gradient tube readings, then it would be assumed that the difference was due to additional offset equivalent to 0.2Ω of bridge resistance. The bridge resistance offset then is estimated as

$$\Delta R_B = -0.8 + 1.99\ (TR-TA)_{mean} \quad \text{ohms}$$

$$\text{or } \Delta TR = -0.4 + (TR-TA)_{mean} \quad {}^\circ K$$

This value is tabulated on the performance criteria sheet for each ring bridge. (See form in Section 8.1.4).

4.2.1.2 Temperature Difference

The additional "zero offset" for the ring bridge is obtained during ADL testing. This value is obtained by scaling the gradient tube temperature difference to predict a temperature difference for the ring bridge for "near zero" ΔT tests.

The predicted temperature difference then is:

$$(DTR)_{predicted} = F \frac{(LR)}{(LA)} (DTA)$$

where

$$F = \frac{8900}{8900 + 5280\left(\frac{100}{TR}\right)^3}$$

(Derivation for F factor given in Section 4.2.3.1). The offset then is the mean value of the difference between predicted and indicated values for DTR in all "near zero" ΔT tests. Once the offset is determined, all the values of DTR are corrected accordingly. The mean offset and the standard deviation of offsets from the mean are tabulated on the performance criteria data sheet (Section 8.1.4).

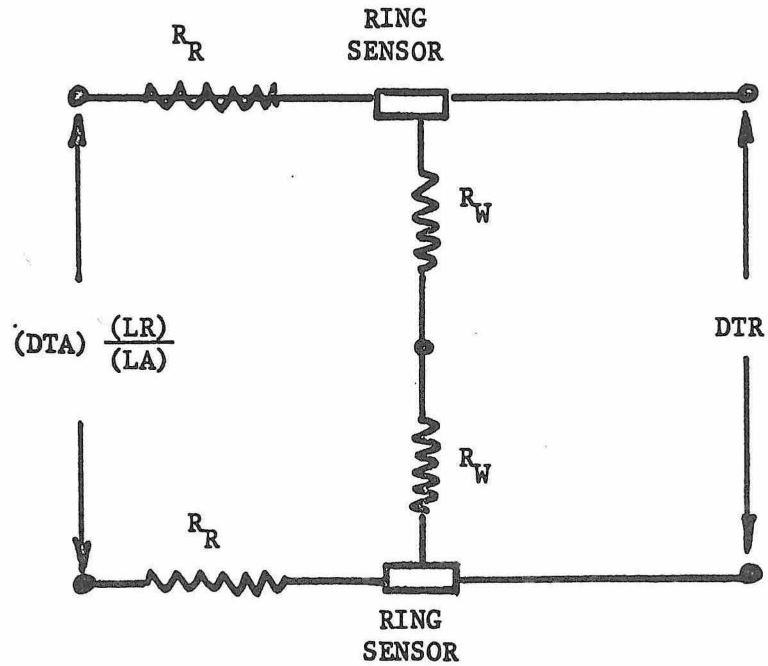
4.2.2 Absolute Average Temperature (corrected for offset)

The standard deviation of the differences between TA and TR, following offset correction, is used as a performance criterion for absolute temperature measurement.

4.2.3 Differential Temperature (corrected for offset)

4.2.3.1 Ring Bridge Shorting Factor

The ring sensors are connected by four heavy interbridge lead wires which tend to produce additional shorting (with respect to overall shorting of the probe assembly between gradient sensors) in the ring bridge region. The model assumes that the ring bridge acts as a separate unit and ignores the coupling between the ring sensors and the epoxy-fiberglass probe body. The ring sensor is radiatively coupled to the surroundings, in this case, the gradient tube of the temperature gradient apparatus. For simplification, we assume it is not thermally connected to the probe body. The ring sensors are connected to each other by the bridge leads which run inside the outer probe body wall. Since the surface area of these wires is small, we neglect radiative coupling of the wires to the surroundings. The model then becomes:



$$F = \left(\frac{DTR}{DTA}\right)\left(\frac{LA}{LR}\right) = \frac{R_W}{R_R + R_W}$$

For purposes of the model, we assume the ring sensor guard acts as the effective radiation area and that it has an emittance of 0.95. Then

$$R_R = \frac{1}{4\sigma\epsilon T^3 A} = \frac{1}{4(5.67 \times 10^{-12})\ (.95)\ T^3\ (8.8)} = \frac{5280}{\left(\frac{T}{100}\right)^3}\ \frac{°K}{Watt}$$

The four #23 Karma bridge leads have a half length of about 5.5 in. and each wire has a resistance of 3500 $\frac{°K}{Watt\text{-}cm}$. Therefore

$$R_W = \frac{5.5\ (2.54)\ (3500)}{4} = 8900\ \frac{°K}{Watt}$$

and $$F = \frac{8900}{\left\{8900 + \frac{5280}{\left(\frac{T}{100}\right)^3}\right\}}$$

4.2.3.2 "Best Line" Analysis

The data from the tests conducted at nominal ΔT's of $\pm$ 2° and $\pm$ 20°K are used to estimate the ratio (DTR/DTA) after DTR has been corrected for offset. These values are tabulated in Column 9 of the data summary sheet. Following a similar procedure to that used for the gradient sensor data (Section 4.1.2.1), a "best line" is found for this ratio as a function of absolute temperature (TR). The equation for the "best line" and the standard deviation of individual test points (for nominal $\pm$ 2° ΔT tests only) from this line are indicated on the performance criteria sheet. Individual deviations from the "best line" are presented in Column 10 of the data summary sheet. (Note that the ring sensors operate outside their calibrated range in the nominal $\pm$ 20° ΔT tests.)

4.2.3.3 Length Criteria

In addition, the shorting ratio data are used to calculate an experimental value for the F-factor (at 225°K) described in Section 4.2.3.1. The value of the F-factor, computed using the "best line" value for $\frac{DTR}{DTA}$ at 225°K and the length ratio, is estimated by first computing the length ratio:

$$\text{Length ratio} = \frac{LR}{LA}$$

and then the sorting ratio:

$$\text{Shorting ratio (or F-factor)} = \frac{\text{"Best Line" Ratio at 225°K}}{\text{Length Radio}}$$

This last ratio is used as a performance criterion and is given on the ring bridge performance criteria sheet. The model predicts a value of .95 for the F-factor at 225°K.

5.0 Reduction of "K Apparatus" Test Data

5.1 Mode 2 Tests (Low Conductivity Range)

The Mode 2 test involves actuation of one of the probe heaters at a .002 w power level. Subsequently, the gradient bridge at the corresponding location is read out at various time intervals (see Test Procedures No. 0501, Part II, Section 4.0).

The gradient sensor data is reduced according to the procedures outlined in Section 3.2.1 or 3.3.1, depending on whether or not probe electronics are used. The temperature rise of the sensor under the heater is tabulated as a function of time.

5.2 Mode 3 Tests (High Conductivity Range)

The Mode 3 test involves actuation of one of the probe heaters at a 0.5 w power level. Subsequently, the ring bridge at the corresponding location is read out at frequent time intervals. Ring bridge data is reduced according to the procedures outlined in Section 3.2.2.2 or 3.3.2 depending on whether or not probe electronics are used. The temperature rise of the ring sensor nearest the heater is tabulated as a function of time.

6.0 Interpretation of "K Apparatus" Test Data

6.1 Mode 2 Tests

The thermal conductivity of the probe's surroundings is related to the steady-state temperature of the gradient sensor lying beneath the actuated heating element. The actual relationship between temperature and thermal conductivity is based both on comparison with Arthur D. Little, Inc. test data and upon models presently being developed from analog model analysis (Columbia University Heat and Mass Transfer Laboratory) sponsored by the principal investigator, Dr. Langseth.

6.2 Mode 3 Tests

Thermal conductivity is related to the transient response and signal amplitude indicated by the ring sensor following actuation of the nearest heater in Mode 3. Again, interpretation of results is based upon comparison of response curves with previous experimental data and with analog model predictions (Columbia University, sponsored by Dr. Langseth). In the "K Apparatus" the simulated lunar materials are retained by an epoxy-fiberglass sheath into which the probe is inserted. Since the thermal conductivity of the sheath corresponds to that of the highest anticipated lunar conductivity, appreciable shorting down the sheath occurs. This effect must be separated out to enable an estimate of the conductivity of the parallel "lunar" path to be made. Originally, it was anticipated that this effect would be present only during testing and that the actual lunar hole would be unlined. Subsequently, it has been deemed necessary to line the hole for the lunar experiment also. Therefore, interpretation of lunar data should be quite similar to that of "K Apparatus" data if the liners are of similar construction. The "K Apparatus" configuration has been simulated in an analog model analysis along with simulations for an unlined lunar hole.

7.0 Recommended Procedures for Subsequent Probe Data Reduction and Interpretation

7.1 Gradient Sensors

Basic data reduction procedures are the same as those described in Section 3.3.1.

7.1.1 Transient Behavior

Probe absolute average temperature represents the absolute average temperature of the surroundings in a steady state environment. In a transient environment, the probe absolute temperature lags the environment in a manner indicated approximately in Figure 7.1 which shows typical probe response (dotted lines) to changes in absolute temperature imposed using the ΔT Apparatus gradient tube. The probe lags by about 40 minutes in this test.

Transient response to a changing temperature difference across a probe half is shown in Figures 7.2 to 7.4. Again, about a 20-30 minute probe response time is indicated. Full interpretation of probe performance in a transient environment requires sophisticated modeling which would be provided, if it should be necessary, by the principal investigator in the final interpretation of lunar data.

7.1.2 Probe Shorting Model Applied to Environment with Spreading Resistance

The model described in Section 4.1.2.2 may be modified to approximate probe shorting performance in a low conductivity environment--e.g., lunar material.

Heat loss from the fin is described by a coefficient h, which can be corrected to include the additional effect of a "spreading" resistance outside the radiative resistance.

Since the radiation resistance has been linearized and is in series with the spreading resistance, R_{sp}, the two resistances may be added to give the total resistance. This is not an exact procedure, since the value of R_{sp} is assumed to be uniform around the probe, while, in fact, R_{sp} becomes uniformly distributed only at the large distances

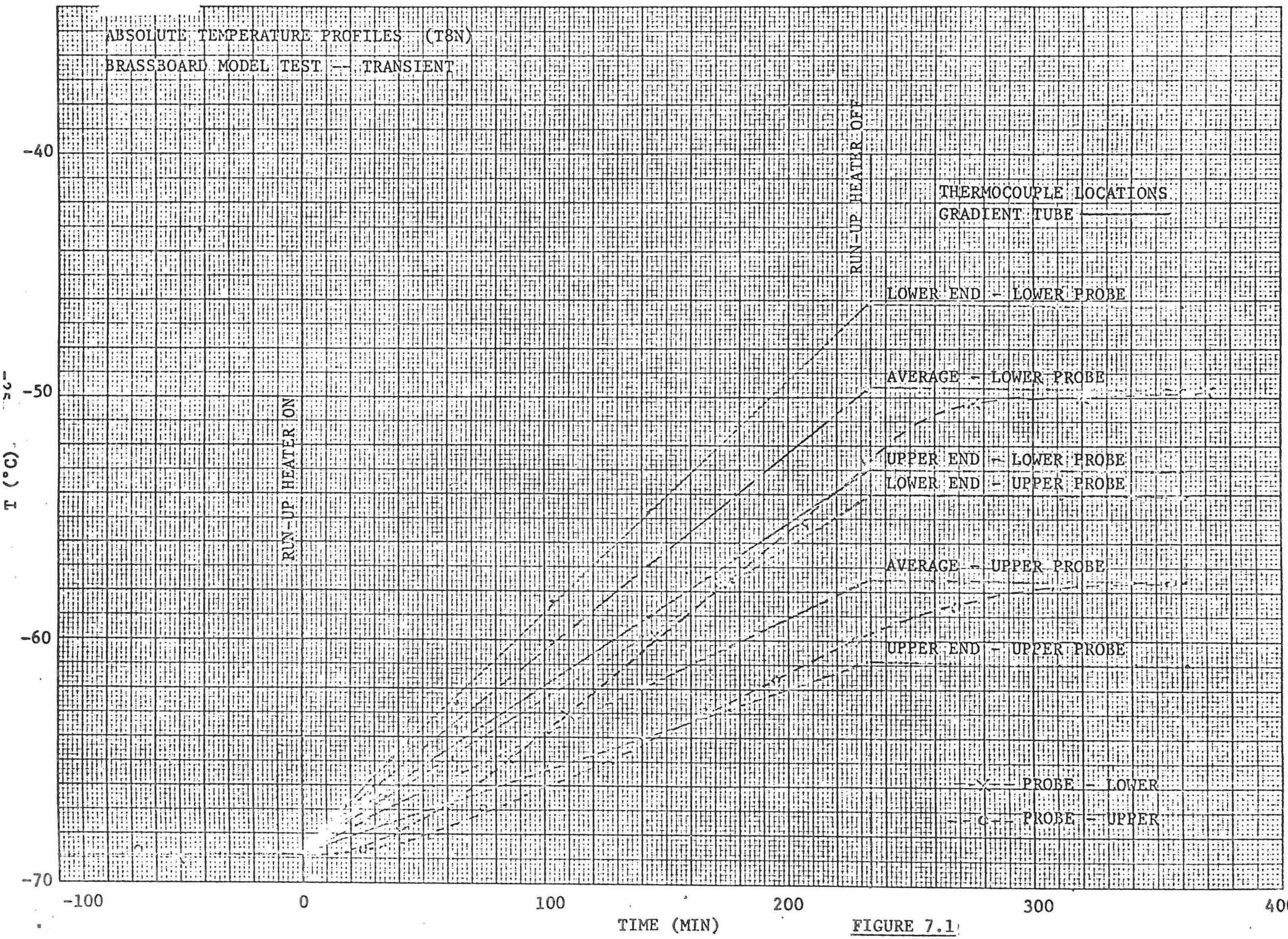

ABSOLUTE TEMPERATURE PROFILES (T8N)
BRASSBOARD MODEL TEST -- TRANSIENT
RUN-UP HEATER ON
RUN-UP HEATER OFF
THERMOCOUPLE LOCATIONS
GRADIENT TUBE
LOWER END - LOWER PROBE
AVERAGE - LOWER PROBE
UPPER END - LOWER PROBE
LOWER END - UPPER PROBE
AVERAGE - UPPER PROBE
UPPER END - UPPER PROBE
PROBE - LOWER
PROBE - UPPER
T (°C)
-40
-50
-60
-70
-100
0
100
200
300
400
TIME (MIN)

FIGURE 7.1

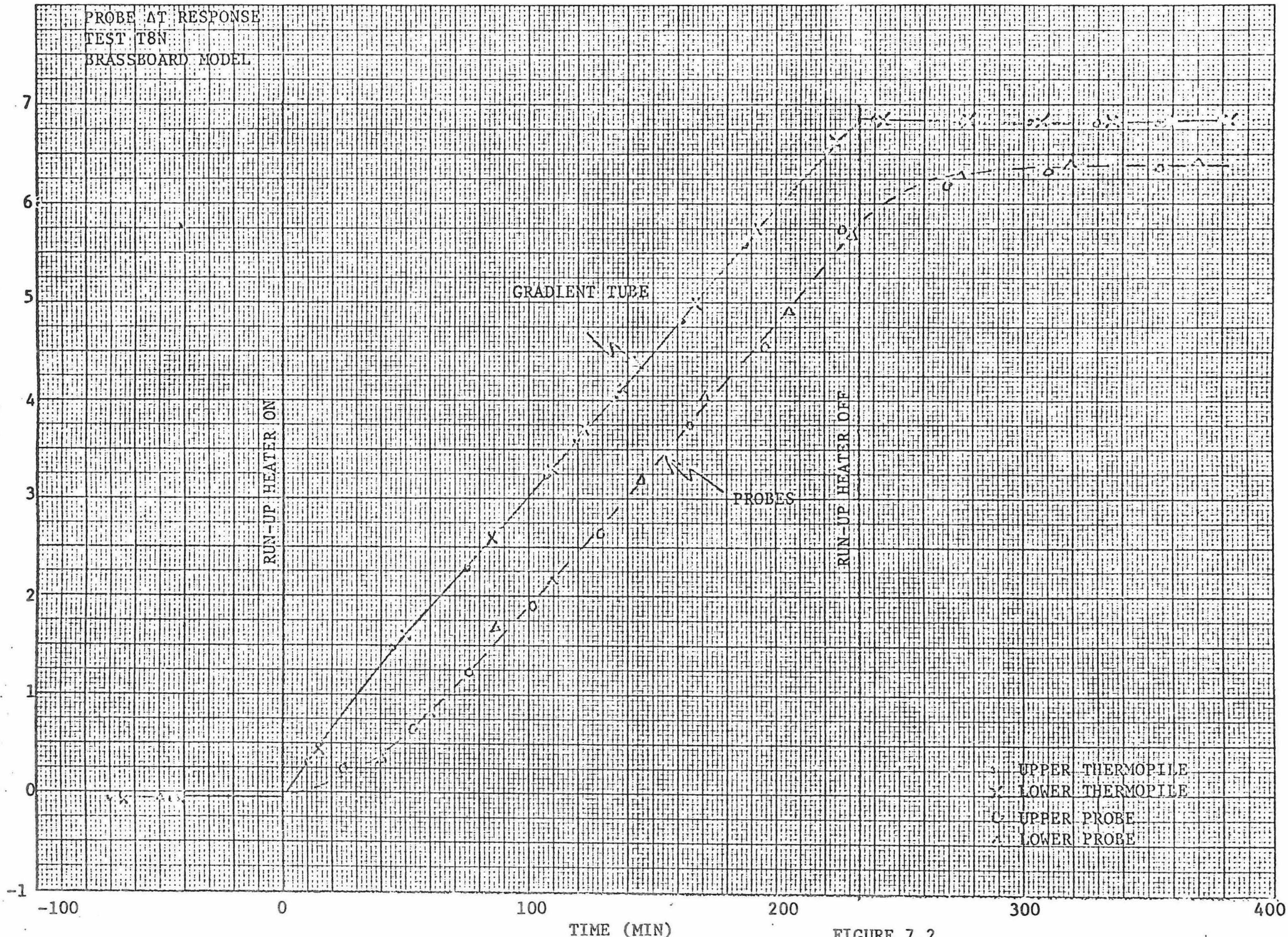
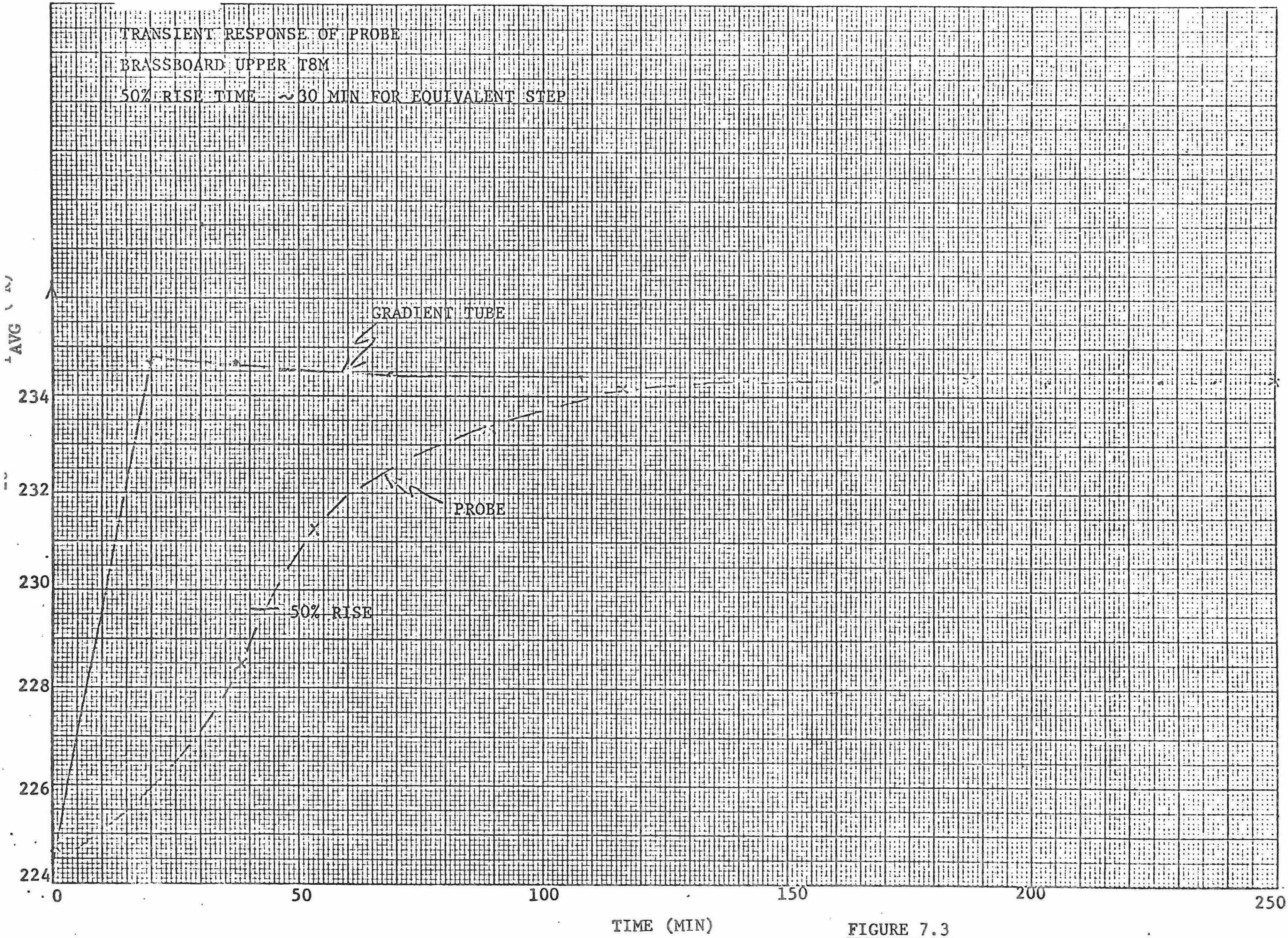

PROBE ΔT RESPONSE
TEST T8N
BRASSBOARD MODEL
GRADIENT TUBE
PROBES
RUN-UP HEATER ON
RUN-UP HEATER OFF
UPPER THERMOPILE
LOWER THERMOPILE
UPPER PROBE
LOWER PROBE
ΔT (°K)
TIME (MIN)
-1
0
1
2
3
4
5
6
7
-100
0
100
200
300
400

FIGURE 7.2



TRANSIENT RESPONSE OF PROBE
BRASSBOARD UPPER T8M
50% RISE TIME ~30 MIN FOR EQUIVALENT STEP
GRADIENT TUBE
PROBE
50% RISE
AVG
234
232
230
228
226
224
0
50
100
150
200
250
TIME (MIN)

FIGURE 7.3

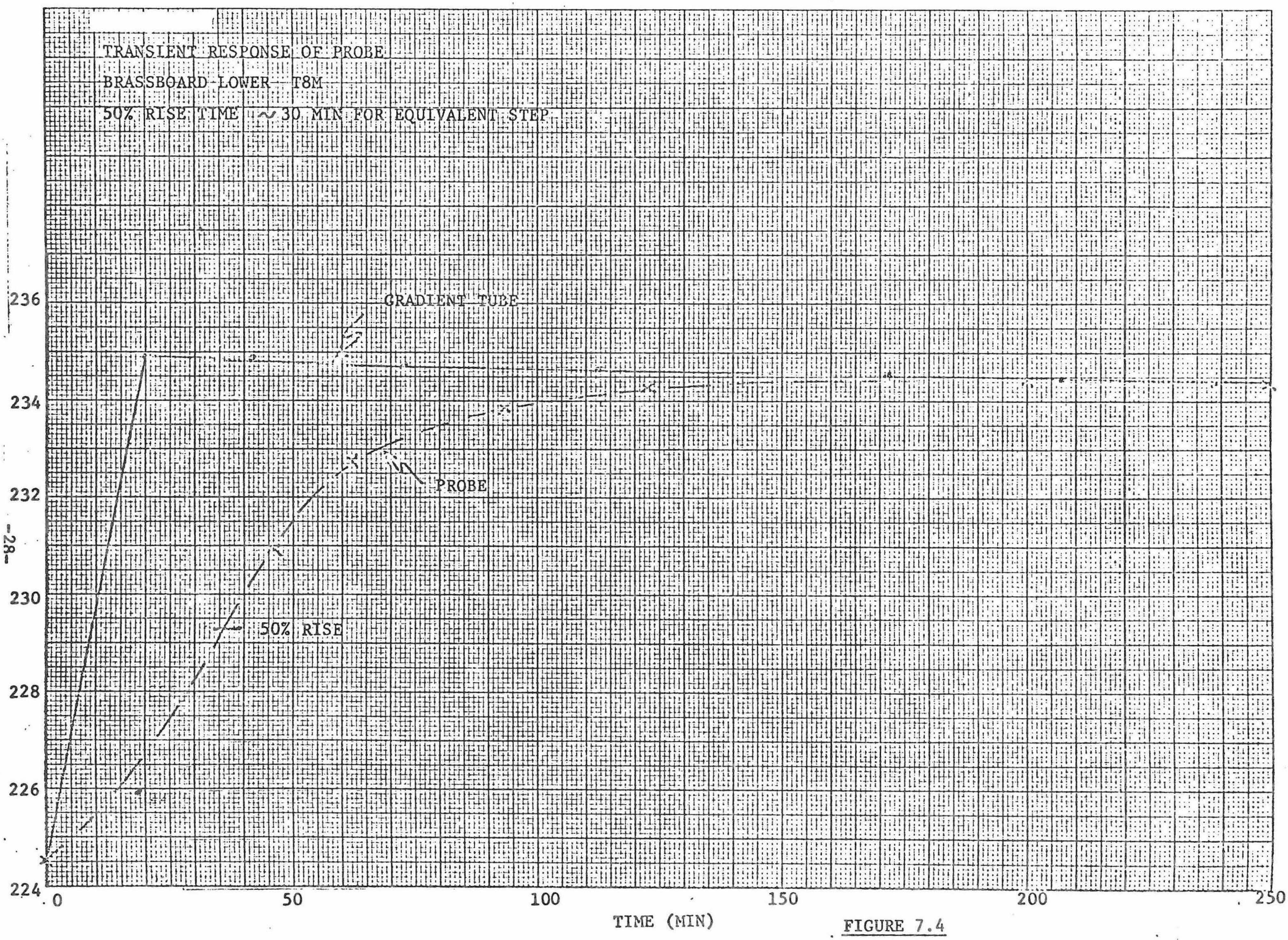

TRANSIENT RESPONSE OF PROBE
BRASSBOARD LOWER T8M
50% RISE TIME ~30 MIN FOR EQUIVALENT STEP
GRADIENT TUBE
PROBE
50% RISE
236
234
232
230
228
226
224
0
50
100
150
200
250
TIME (MIN)

FIGURE 7.4

from the probe. However, this technique may be used to obtain a reasonable idea of lunar performance. In interpretation of actual lunar data, the true system geometry should be treated more exactly (probably by a two-dimensional computer model, if spreading resistance is large in comparison to radiation resistance) to ge the best estimate of undisturbed lunar temperature distribution.

In a lunar material of thermal conductivity k_L (watts/cm °K), spreading resistance for a half probe may be modeled in several approximate ways which have been presented in Appendix 5, Design Definition of Heat Flow Probe (report to Bendix by Arthur D. Little, Inc., August 17, 1966).

a. Isothermal sphere

$$R_s = \frac{1}{4\pi a k_L} \qquad a = \text{equivalent radius of borehole} \tag{1}$$

b. Isothermal long cylinder of length = 2L and radius = a

$$R_s = \frac{1}{4\pi L k_L} \quad \ln\left(\frac{2L}{a}\right) \tag{2}$$

c. Isothermal prolate spheroid (major axis = 2L, minor axis = 2a)

$$R_s = \frac{1}{8\pi k_L \sqrt{L^2 - a^2}} \quad \ln \frac{L + \sqrt{L^2 - a^2}}{L - \sqrt{L^2 - a^2}} \tag{3}$$

A half probe is about 21" long and the borehole diameter is nominally 1". Using these dimensions, the values of spreading resistance computed for Models b and c are:

TABLE I

ESTIMATES OF LUNAR SPREADING RESISTANCE

K_L $(\frac{\text{watts}}{\text{cm °K}})$	R_{sp} (°K/watt) Model B	R_{sp} (°K/watt) Model C
2×10^{-5}	455	600
4×10^{-5}	228	280
4×10^{-4}	22.8	28
4×10^{-3}	2.3	2.8

The maximum value for spreading resistance of the lowest conductivity lunar material around a probe half appears to be about 600°K/watt. These spreading resistances are in series with a radiation resistance which varies with probe temperature level.

TABLE II

ESTIMATES OF PROBE HALF RADIATION RESISTANCE

T_{AVG} (°K)	R_R (°K/WATT)
200	19.2
225	13.5
250	9.85

As has been noted before, in a highly conductive moon, radiation resistance predominates. At the low end of probable lunar conductivities, spreading resistance controls probe shorting in a steady heat flow field.

7.1.3 Error Analysis for Lunar Measurement

a. Errors in $\frac{X}{L}$ Determination

Experimental data from ΔT apparatus tests are used to compute the "effective probe length", 2X, which will be used subsequently to interpret lunar data. Uncertainties in the determination of X, due both to experimental error and inadequacies in the model, will introduce an error into the interpretation of lunar data. In the "lowest K" moon, a measurement with the "highest K" probe (upper half) should allow lunar $(\Delta T_o/2X)$ to be estimated with less than 5% error.

Starting with eq. 24 (Section 4.1.2.2) and basing ΔT values on a measuring length of 2X:

$$\frac{\Delta T_{probe}}{\Delta T_{o\ moon}} = 1 - \frac{1}{mL}\left(\frac{L}{X}\right)\frac{e^{-mL\left(1-\frac{X}{L}\right)}}{\left(1+mL\frac{D}{4L}\right)} \tag{4}$$

$$\frac{\partial}{\partial\left(\frac{X}{L}\right)}\cdot\left(\frac{\Delta T_{probe}}{\Delta T_{o\ moon}}\right) = \frac{e^{-mL\left(1-\frac{X}{L}\right)}}{\left(1+mL\frac{D}{4L}\right)}\left[\frac{1}{mL}\left(\frac{L}{X}\right)^2 - \left(\frac{L}{X}\right)\right] \tag{5}$$

The worst case is for lowest K_L and an upper half probe:

$$R_p = 10{,}950$$

$$R_R + R_{sp} = 650 \text{ (conservative estimate)}$$

Typical values of $\frac{X}{L}$ (based on Engineering Model 2 data):

$$\frac{X}{L} \approx .865 \qquad \frac{D}{4L} \approx \frac{1}{40}$$

$$mL = \left[\frac{10{,}950}{2{,}600}\right]^{1/2} = 2.1$$

(Note that this is the minimum value of mL which would be obtained in the operating range. Eq. 16 (Section 4.1.2.2) was simplified by assuming mL and mx >> 1, so that e^{-mL} could be neglected in comparison to e^{mL}. For this case, the error introduced by the simplification is equivalent to neglecting .122 relative to 8.17 or about a 1.5% error. For more exact results, eq. 16 should be used.

To compute allowable $(\frac{X}{L})$ for a 5% error in T_o(moon):

$$\Delta\left(\frac{X}{L}\right) = \frac{1}{\frac{\partial}{\partial(\frac{X}{L})}\left(\frac{\Delta T_{probe}}{\Delta T_{o\ moon}}\right)} (.05) \left(\frac{\Delta T_{probe}}{\Delta T_{o\ moon}}\right) \qquad (6)$$

For the above conditions (worst case):

$$\Delta\left(\frac{X}{L}\right) = .115 \qquad (7)$$

or a 10% error in $\frac{X}{L}$ can cause about a 5% error in ΔT_o (moon) estimation. For the Engineering Model 2 probe, the standard deviation in $\frac{X}{L}$ is less than 1/2%.

b. Errors in Spreading Resistance Estimate and/or Probe Conductance

An uncertainty in either probe resistance or spreading resistance results in an uncertainty in the value of mL. Starting again with equation 4, we obtain

$$\frac{\partial}{\partial(mL)}\left(\frac{\Delta T_{probe}}{\Delta T_{o\ moon}}\right) = \frac{e^{-mL(1-\frac{X}{L})}}{(1+\frac{mL\ D}{4L})}\left[\frac{1}{(mL)^2}\left(\frac{L}{X}\right) + \frac{(1-\frac{X}{L})\frac{L}{X}}{mL}\right] \quad (8)$$

where variation in the $(mL \frac{D}{4L})$ term has been neglected due to its small effect.

Again, for a 5% error in ΔT_o (moon) attributed solely to an error in mL, we find for the worst case conditions set forth in the previous section:

$$\Delta(mL) = \frac{1}{\frac{\partial}{\partial(mL)}\left(\frac{\Delta T_{probe}}{\Delta T_{o\ moon}}\right)} \quad .05 \quad \left(\frac{\Delta T_{probe}}{\Delta T_{o\ moon}}\right) \quad (9)$$

or $\Delta(mL) = .188$

Since $mL \approx 2.1$, the error on mL is about 11.5%. But $mL \propto \left(\frac{R_P}{R_{sp}}\right)^{1/2}$, so about a 20% error in the resistance ratio could be tolerated for a 5% inaccuracy in ΔT_o(moon).

In the actual experiment, an overall error of 5% is allowed. A probable allocation of error among the major factors might be:

$\Delta\frac{X}{L}$	1%
ΔR_P	5%
ΔR_{sp}	15%

7.2 Ring Sensors

Data reduction for ring sensors involves the following steps:

7.2.1 Reduce probe output data to R_B and $^{Eo}/Ei$ using procedures involving the electronics calibration constants as described in Section 3.3.2.

7.2.2 Add ΔR_B shown for performance criteria sheet to indicate R_B and use $(R_B + \Delta R_B)$ and $^{Eo}/Ei$ to solve for TR and DTR following the procedure presented in Section 3.2.1. TR is the final value of absolute average temperature.

7.2.3 Add "zero offset" shown on performance criteria sheet to value of DTR found in 7.2.2 to obtain final value of DTR, ring bridge temperature difference.

7.3 Reference Junction

After using electronics data reduction procedures described in Section 3.3.3, the cubic equation shown in this Section is solved for TCR using the calibration constants tabulated on the reference junction calibration constant data sheet.

7.4 Thermocouples

Data reduction for thermocouples follows procedures described in Section 3.3.4.

8.0 APPENDIX

8.1 Data Summary Forms

8.1.1 Calibration Constants

8.1.2 Test Data Summary

8.1.3 Performance Criteria: Gradient Bridge

8.1.4 Performance Criteria: Ring Bridge

HEAT FLOW PROBE PROGRAM

Bondix Contract SC 0242

Caso 68647 5

CALIBRATION CONSTANTS

PROBE HALF F2-1 UPPER

S/N 2227

GRADIENT BRIDGE

DATE 1-17-69

Rosemount Engineering Co. Calibration Constants*

R_B		$R_B \frac{Eo}{Ei}$	
C1 =	.50283517 E+03	C7 =	-.93077231 E-03
C2 =	.19906413 E+01	C8 =	.10540685 E-02
C3 =	-.35851658 E-03	C9 =	.17308874 E-05
C4 =	.12335796 E-09	C10 =	-.99643045
C5 =	.99494169	C11 =	.14726895 E-03
C6 =	-.17931699 E-03	C12 =	.11089460 E-08

TOTAL EXCITATION LEAD RESISTANCE = 1077.0 Ω

Electronics F2 CHANNEL 1

P 1 k = .0054410 R = 201,100 ohm

P 5 k = 19.999 ohm

P 9 k = .0027216 mho

CENTERLINE SEPARATION OF SENSORS AT 225°K 18.633 in.

* For ring bridge, a correction factor is determined during ADL tests to determine offset in R_B and $R_B \frac{Eo}{Ei}$ due to shortening of interbridge leads following Rosemount Engineering Co. calibration

Arthur D. Little, Inc.

HEAT FLOW PROBE PROGRAM

Bendix Contract SC 0242

Case 68647 5

CALIBRATION CONSTANTS

PROBE HALF F2-1 LOWER

S/N 2223

GRADIENT BRIDGE

DATE 1-17-69

Rosemount Engineering Co. Calibration Constants*

R_B		$R_B \frac{Eo}{Ei}$	
C1 =	.50260460 E+03	C7 =	-.35255229 E-01
C2 =	.19921590 E+01	C8 =	-.57939902 E-05
C3 =	-.32803215E-03	C9 =	.25410139 E-06
C4 =	-.75261940 E-09	C10 =	-.99693372
C5 =	.99646929	C11 =	.14682064 E-03
C6 =	-.16561668 E-03	C12 =	.10744480 E-08

TOTAL EXCITATION LEAD RESISTANCE = 1168.0 Ω

Electronics F2 CHANNEL 1

P 2 k = .0054404 R = 201100 ohm

P 6 k = 20.000 ohm

P 10 k = .0027216 mho

CENTERLINE SEPARATION OF SENSORS AT 225°K 18.630 in.

* For ring bridge, a correction factor is determined during ADL tests to determine offset in R_B and $R_B \frac{Eo}{Ei}$ due to shortening of interbridge leads following Rosemount Engineering Co. calibration

Arthur D. Little, Inc.

HEAT FLOW PROBE PROGRAM

Bondix Contract SC 0242

Caso 68647 5

CALIBRATION CONSTANTS

PROBE HALF F2-1 UPPER

S/N 2227

RING BRIDGE

DATE 1-17-69

Rosemount Engineering Co. Calibration Constants*

R_B		$R_B \frac{Eo}{Ei}$	
C1 =	.50260903 E+03	C7 =	-.96950268 E-02
C2 =	.19912469 E+01	C8 =	-.55975792 E-04
C3 =	-.30425533 E-03	C9 =	-.12089968 E-06
C4 =	-.18655941 E-08	C10 =	-.99590559
C5 =	.99448996E00	C11 =	.14895210E-03
C6 =	-.17708257E-03	C12 =	.10721814 E-08

TOTAL EXCITATION LEAD RESISTANCE = 1126.7 Ω

Electronics F2 CHANNEL 1

P 13 k = .0054403 R = 201100 ohm

P NA k = NA ohm

P 17 k = .0027218 mho

CENTERLINE SEPARATION OF SENSORS AT 225°K 11.2976 in.

* For ring bridge, a correction factor is determined during ADL tests to determine offset in R_B and $R_B \frac{Eo}{Ei}$ due to shortening of interbridge leads following Rosemount Engineering Co. calibration

Arthur D. Little, Inc.

HEAT FLOW PROBE PROGRAM

Bendix Contract SC 0242

Case 68647 5

CALIBRATION CONSTANTS

PROBE HALF F2-1 LOWER

S/N 2223

RING BRIDGE

DATE 1-17-69

Rosemount Engineering Co. Calibration Constants*

R_B		$R_B \frac{Eo}{Ei}$	
C1 =	.50249089 E+03	C7 =	.29187223 E-01
C2 =	.19914240 E+01	C8 =	.17566751 E-03
C3 =	-.29350295E-03	C9 =	.78260945 E-06
C4 =	-.22636361.E-08	C10 =	-.99574664
C5 =	.99161845	C11 =	.14487020 E-03
C6 =	-.20129711 E-03	C12 =	.12173943 E-08

TOTAL EXCITATION LEAD RESISTANCE = 1196.3 Ω

Electronics F2 CHANNEL 1

P 14 k = 0.0054408 R = 201100 ohm

P N.A k = N.A. ohm

P 18 k = .0027221 mho

CENTERLINE SEPARATION OF SENSORS AT 225°K 11.2926 in.

* For ring bridge, a correction factor is determined during ADL tests to determine offset in R_B and $R_B \frac{Eo}{Ei}$ due to shortening of interbridge leads following Rosemount Engineering Co. calibration

Arthur D. Little, Inc.

HEAT FLOW PROBE PROGRAM

Bendix Contract SC 0242

Case 68647 5

CALIBRATION CONSTANTS

PROBE HALF F2-2 UPPER

S/N 2230

GRADIENT BRIDGE

DATE 1-17-69

Rosemount Engineering Co. Calibration Constants*

R_B	$R_B \frac{Eo}{Ei}$
C1 = .50307569 E+03	C7 = -.14818260 E-02
C2 = .19953227 E+01	C8 = .92972487 E-03
C3 = -.28122422 E-03	C9 = .11907944 E-05
C4 = -.25963509 E-08	C10 = -.99692788
C5 = .99598375	C11 = .14755965 E-03
C6 = -.17211667 E-03	C12 = .10907321 E-08

TOTAL EXCITATION LEAD RESISTANCE = 1081.9 Ω

Electronics F2 CHANNEL 2

P 3 k = .0054407 R = 201,100 ohm

P 7 k = 20.000 ohm

P 11 k = .0027218 mho

CENTERLINE SEPARATION OF SENSORS AT 225°K 18.6256 in.

* For ring bridge, a correction factor is determined during ADL tests to determine offset in R_B and $R_B \frac{Eo}{Ei}$ due to shortening of interbridge leads following Rosemount Engineering Co. calibration

HEAT FLOW PROBE PROGRAM

Bendix Contract SC 0242

Case 68647 5

CALIBRATION CONSTANTS

PROBE HALF F2-2 LOWER

S/N 2226

GRADIENT BRIDGE

DATE 1-17-69

Rosemount Engineering Co. Calibration Constants*

R_B	$R_B \frac{Eo}{Ei}$
C1 = .50255942E+03	C7 = .15078971E-02
C2 = .19947705E+01	C8 = -.42123937E-05
C3 = -.26975965E-03	C9 = -.51960473E-07
C4 = -.28660648E-08	C10 = -.99678507
C5 = .99561325	C11 = .14637729E-03
C6 = -.17270703E-03	C12 = .11019331E-08

TOTAL EXCITATION LEAD RESISTANCE = 1161.4 Ω

Electronics F2 CHANNEL 2

P 4 k = .0054411 R = 201,100 ohm

P 8 k = 20.001 ohm

P 12 k = .0027220 mho

CENTERLINE SEPARATION OF SENSORS AT 225°K 18.631 in.

* For ring bridge, a correction factor is determined during ADL tests to determine offset in R_B and $R_B \frac{Eo}{Ei}$ due to shortening of interbridge leads following Rosemount Engineering Co. calibration

Arthur D. Little, Inc.

HEAT FLOW PROBE PROGRAM

Bondix Contract SC 0242

Caso 68647 5

CALIBRATION CONSTANTS

PROBE HALF F2-2 UPPER

S/N 2230

RING BRIDGE

DATE 1-17-69

Rosemount Engineering Co. Calibration Constants*

R_B		$R_B \frac{Eo}{Ei}$	
C1 =	.50262273 E+03	C7 =	-.88912982 E-01
C2 =	.19917697 E+01	C8 =	-.66888112 E-04
C3 =	-.29688777 E-03	C9 =	-.35718330 E-06
C4 =	-.20684227 E-08	C10 =	-.99634725
C5 =	.99555806	C11 =	.14254283 E-03
C6 =	-.17031117 E-03	C12 =	.12188802 E-08

TOTAL EXCITATION LEAD RESISTANCE = 1110.0 Ω

Electronics F2 CHANNEL 2

P 15 k = .0054409 R = 201,100 ohm

P N.A. k = N.A. ohm

P 19 k = .0027223 mho

CENTERLINE SEPARATION OF SENSORS AT 225°K 11.299 in.

* For ring bridge, a correction factor is determined during ADL tests to determine offset in R_B and $R_B \frac{Eo}{Ei}$ due to shortening of interbridge leads following Rosemount Engineering Co. calibration

Arthur D. Little, Inc.

HEAT FLOW PROBE PROGRAM

Bondix Contract SC 0242

Caso 68647 5

CALIBRATION CONSTANTS

PROBE HALF F2-2 LOWER

S/N 2226

RING BRIDGE

DATE 1-17-69

Rosemount Engineering Co. Calibration Constants*

R_B	$R_B \frac{Eo}{Ei}$
C1 = .50254738E+03	C7 = .84565417E-02
C2 = .19908309E+01	C8 = -.15647423E-03
C3 = -.30678575E-03	C9 = -.38101429E-06
C4 = -.17677907E-08	C10 = -.99618221
C5 = .99448607	C11 = .14457960E-03
C6 = -.16945546E-03	C12 = .1121547E-08

TOTAL EXCITATION LEAD RESISTANCE = 1197.4 Ω

Electronics F2 CHANNEL 2

P 16 k = .0054406 R = 201,100 ohm

P N.A k = N.A ohm

P 20 k = .0027221 mho

CENTERLINE SEPARATION OF SENSORS AT 225°K 11.279 in.

* For ring bridge, a correction factor is determined during ADL tests to determine offset in R_B and $R_B \frac{Eo}{Ei}$ due to shortening of interbridge leads following Rosemount Engineering Co. calibration

Arthur D. Little, Inc.

PROBE HALF F2-1

S/N 2227

GRADIENT BRIDGE (Upper)

OFFICIAL ACCEPTANCE DATA

HEAT FLOW PROBE PROGRAM

Bendix Contract SC 0242

Case 68647 5

NOTE: Ring data include offset corrections.

TEST DATA SUMMARY

1 TEST NO.	2 NOMINAL CONDITIONS T/DT*	3 DATE	4 TA 01 (°K)	5 T G11 (°K)	6 5 - 4 ERROR T	7 DTA 01 (°K)	8 DT G11 (°K)	9 8 / 7	10 DEVIATION FROM "BEST LINE" (°K)
T73A	245/2E	12/ 9/68	242.809	242.811	.002	2.1096	2.0140	.9547	-.0013
T35C	245/2	1/ 5/68	243.309	243.299	-.010	1.7979	1.7203	.9568	.0028
T73B	225/18E	12/11/68	213.973	213.995	.021	17.7228	16.7804	.9468	.0179
T35A	205/-2	1/ 2/68	205.501	205.551	.050	-2.0909	-1.9776	.9458	.0008
								ΔT OFFSET (Zero ΔT Tests)	
T35B	225/0	1/ 4/68	224.423	224.464	.041	.0290	.0280	.000	

* E designates tests run with probe electronics.

36-1

Arthur D. Little, Inc.

PROBE HALF F2-1

S/N 2223

GRADIENT BRIDGE (Lower)

OFFICIAL ACCEPTANCE DATA

HEAT FLOW PROBE PROGRAM

Bendix Contract SC 0242

Case 68647 5

NOTE: Ring data include offset corrections.

TEST DATA SUMMARY

1 TEST NO.	2 NOMINAL CONDITIONS T/DT*	3 DATE	4 TA 02 (°K)	5 T G12 (°K)	6 5 - 4 ERROR T	7 DTA 02 (°K)	8 DT G12 (°K)	9 8 / 7	10 DEVIATION FROM "BEST LINE" (°K)
T73A	245/2E	12/ 9/68	245.243	245.236	-.008	2.0802	1.9693	.9467	-.0010
T35C	245/2	1/ 5/68	245.385	245.406	.021	1.7680	1.6758	.9479	.0012
T73B	225/18E	12/11/68	234.278	234.556	(.278-.2 = .078)	17.3323	16.3611	.9440	.0158
T35A	205/-2	1/ 2/68	203.065	203.081	.016	-2.1401	-2.0074	.9380	.0002
								ΔT OFFSET (Zero ΔT Tests)	
T35B	225/0	1/4/68	224.435	224.475	.040	-.0015	-.0015	.000	

* E designates tests run with probe electronics.

36-2

Arthur D. Little, Inc.

OFFICIAL ACCEPTANCE DATA

HEAT FLOW PROBE PROGRAM

PROBE HALF F2-1

S/N 2227

RING BRIDGE (Upper)

Bendix Contract SC 0242

Case 68647 5

TEST DATA SUMMARY

NOTE: Ring data include offset corrections.

ΔT OFFSET = .0224°K

T OFFSET = .40°K

1 TEST NO.	2 NOMINAL CONDITIONS T/DT*	3 DATE	4 TA 01 (°K)	5 T R11 (°K)	6 5 - 4 ERROR T	7 DTA 01 (°K)	8 DT R11 (°K)	9 8 / 7	10 DEVIATION FROM "BEST LINE" (°K)
T73A	245/2E	12/ 9/68	242.811	242.831	-.020	2.1097	1.2208	.5787	-.0006
T35C	245/2	1/ 5/68	243.309	243.287	.022	1.7979	1.0426	.5791	.0016
T35A	205/-2	1/ 2/68	205.501	205.513	.012	-2.0909	-1.1879	.5681	.0000
								ΔT OFFSET (Zero ΔT Tests)	
T35B	225/0	1/ 4/68	224.423	224.434	.011	.0290	.0166	.000	

* E designates tests run with probe electronics.

36-3

Arthur D. Little, Inc.

OFFICIAL ACCEPTANCE DATA

PROBE HALF F2-1

S/N 2223

RING BRIDGE (Lower)

HEAT FLOW PROBE PROGRAM

Bendix Contract SC 0242

Case 68647 5

TEST DATA SUMMARY

NOTE: Ring data include offset corrections.

ΔT OFFSET = .0118°K

T OFFSET = .43°K

1 TEST NO.	2 NOMINAL CONDITIONS T/DT*	3 DATE	4 TA 02 (°K)	5 T R12 (°K)	6 5 - 4 ERROR T	7 DTA 02 (°K)	8 DT R12 (°K)	9 8 / 7	10 DEVIATION FROM "BEST LINE" (°K)
T73A	245/2E	12/ 9/68	245.241	245.298	.057	2.0768	1.2067	.5810	.0015
T35C	245/2	1/ 5/68	245.385	245.389	.004	1.7680	1.0292	.5821	-.0006
T35A	205/-2	1/ 2/68	203.065	203.045	-.020	-2.1401	-1.2187	.5691	.0000
								ΔT OFFSET (Zero ΔT Tests)	
T35B	225/0	1/ 4/68	224.435	224.452	.017	-.0015	-.0009	.000	

* E designates tests run with probe electronics.

36-4

Arthur .Little,Inc.

OFFICIAL ACC ANCE DATA

PROBE HALF F2-2

S/N 2230

GRADIENT BRIDGE (UPPER)

HEAT FLOW PROBE PROGRAM

Bendix Contract SC 0242

Case 68647 5

NOTE: Ring data include offset corrections.

TEST DATA SUMMARY

1 TEST NO.	2 NOMINAL CONDITIONS T/DT*	3 DATE	4 TA 01 (°K)	5 T G21 (°K)	6 5 - 4 ERROR T	7 DTA 01 (°K)	8 DT G21 (°K)	9 8 / 7	10 DEVIATION FROM "BEST LINE" (°K)
T36C	245/2	1/10/68	242.469	242.473	.004	2.1095	2.009	.9522	.0004
T74B	245/2E	12/16/68	242.730	242.715	-.014	2.0952	1.9960	.9527	-.0001
T74A	225/18E	12/13/68	213.887	213.933	.046	17.7210	16.7487	.9451	-.0189
T36A	205/-2	1/ 8/68	205.563	205.599	.04	-2.1017	-1.978	.9413	-.0009
								ΔT OFFSET (Zero ΔT Tests)	
T36B	225/0	1/9/68	224.507	224.539	.03	.0618	.058	.001	

* E designates tests run with probe electronics.

36-5

Arthur D. Little, Inc.

PROBE HALF F2-2

S/N 2226

GRADIENT BRIDGE (LOWER)

OFFICIAL ACCEPTANCE DATA

HEAT FLOW PROBE PROGRAM

Bendix Contract SC 0242

Case 63647 5

NOTE: Ring data include offset corrections.

TEST DATA SUMMARY

1 TEST NO.	2 NOMINAL CONDITIONS T/DT*	3 DATE	4 TA 02 (°K)	5 T G22 (°K)	6 5 - 4 ERROR T	7 DTA 02 (°K)	8 DT G22 (°K)	9 8 / 7	10 DEVIATION FROM "BEST LINE" (°K)
T36C	245/2	1/10/68	244.900	244.930	.030	2.0805	1.9753	.9494	-.0005
T74B	245/2E	12/16/68	245.137	245.150	.012	2.0650	1.9585	.9484	.0017
T74A	225/18E	12/13/68	234.198	234.434	{.236-.2 = .036}	17.3382	16.4223	.9472	-.0070
T36A	205/-2	1/8/68	203.121	203.115	-.006	-2.1506	-2.0203	.9394	-.0002
								ΔT OFFSET (Zero ΔT Tests)	
T36B	225/0	1/9/68	224.565	224.592	.03	.0343	.032	.000	

* E designates tests run with probe electronics.

36-6

Arthur .Little,Inc.

OFFICIAL AC TANCE DATA

PROBE HALF F2-2

S/N 2230

RING BRIDGE (UPPER)

HEAT FLOW PROBE PROGRAM

Bondix Contract SC 0242

Case 68647 5

TEST DATA SUMMARY

NOTE: Ring data include offset corrections.
ΔT OFFSET = -.080°K
T OFFSET = .43°K

1 TEST NO.	2 NOMINAL CONDITIONS T/DT*	3 DATE	4 TA 01 (°K)	5 T R21 (°K)	6 5 - 4 ERROR T	7 DTA 01 (°K)	8 DT R21 (°K)	9 8 / 7	10 DEVIATION FROM "BEST LINE" (°K)
T36C	245/2	1/10/68	242.469	242.457	-.012	2.1095	1.2268	.5811	-.0010
T74B	245/2E	12/16/68	242.722	242.780	.058	2.0953	1.2156	.5802	.0021
T36A	205/-2	1/8/68	205.564	205.573	.009	-2.1017	-1.1981	.5691	.0000
								ΔT OFFSET (Zero ΔT Tests)	
T36B	225/0	1/9/68	224.507	224.518	.011	.0618	.0354	.000	

* E designates tests run with probe electronics.

36-7

Arthur D. Little, Inc.

OFFICIAL ACCEPTANCE DATA

PROBE HALF F2-2

S/N 2226

RING BRIDGE (LOWER)

HEAT FLOW PROBE PROGRAM

Bendix Contract SC 0242

Case 68647 5

TEST DATA SUMMARY

NOTE: Ring data include offset corrections.
ΔT OFFSET = -.0113°K
T OFFSET = .42°K

1 TEST NO.	2 NOMINAL CONDITIONS T/DT*	3 DATE	4 TA 02 (°K)	5 T R22 (°K)	6 5 - 4 ERROR T	7 DTA 02 (°K)	8 DT R22 (°K)	9 8 / 7	10 DEVIATION FROM "BEST LINE" (°K)
T36C	245/2	1/10/68	244.900	244.919	.019	2.0805	1.2077	.5802	-.0005
T74B	245/2E	12/16/68	245.139	245.199	.061	2.0645	1.1970	.5798	.0011
T36A	205/-2	1/8/68	203.115	203.093	-.022	-2.1506	-1.2205	.5672	.0000
								ΔT OFFSET (Zero ΔT Tests)	
T36B	225/0	1/9/68	224.565	224.577	.008	.0343	.0197	.000	

* E designates tests run with probe electronics.

36-8

Arthur D. Little, Inc.

PROBE HALF F2-1

S/N 2227

GRADIENT BRIDGE (Upper)

OTHER DATA (UNOFFICIAL)

HEAT FLOW PROBE PROGRAM

Bendix Contract SC 0242

Case 68647 5

NOTE: Ring data include offset corrections.

TEST DATA SUMMARY

1 TEST NO.	2 NOMINAL CONDITIONS T/DT*	3 DATE	4 TA 01 (°K)	5 T G11 (°K)	6 5 - 4 ERROR T	7 DTA 01 (°K)	8 DT G11 (°K)	9 8 / 7	10 DEVIATION FROM "BEST LINE" (°K)
T57A	245/2E	5/ 1/68	242.731	242.734	.004	2.0942	2.0042	.9570	
T61A	245/2E	9/11/68	242.772	242.795	.022	2.0800	1.9895	.9565	
T62A	245/2E	9/16/68	242.501	242.468	-.033	2.0002	1.9118	.9558	
T62B	245/2E	9/20/68	242.333	242.311	-.021	1.9526	1.8655	.9554	
T69A2	245/2	10/31/68	242.696	242.663	-.032	2.0979	2.0045	.9555	
T69A3	245/2	11/ 1/68	242.681	242.661	-.020	2.0987	2.0050	.9553	
T57B	225/18E	5/ 2/68	213.776	213.717	-.059	17.7208	16.8190	.9491	
T65A	225/18E	10/ 2/68	213.641	213.662	.021	17.6823	16.7710	.9485	
T69B	225/18	11/ 4/68	213.932	213.926	-.005	17.7494	16.8230	.9478	

ΔT OFFSET (Zero ΔT Tests)

* E designates tests run with probe electronics.

36-9

Arthur D. Little, Inc.

PROBE HALF F2-1

S/N 2223

GRADIENT BRIDGE (LOWER)

OTHER DATA (UNOFFICIAL)

HEAT FLOW PROBE PROGRAM

Bendix Contract SC 0242

Case 68647 5

NOTE: Ring data include offset corrections.

TEST DATA SUMMARY

1 TEST NO.	2 NOMINAL CONDITIONS T/DT*	3 DATE	4 TA 02 (°K)	5 T G12 (°K)	6 5 - 4 ERROR T	7 DTA 02 (°K)	8 DT G12 (°K)	9 8 / 7	10 DEVIATION FROM "BEST LINE" (°K)
T67A	205/-2E	10/17/68	203.028	203.047	.019	-2.1728	-2.0363	.9372	
T57A	245/2E	5/ 1/68	245.148	245.170	.022	2.0659	1.9602	.9488	
T61A	245/2E	9/11/68	245.177	245.208	.030	2.0538	1.9381	.9437	
T62A	245/2E	9/16/68	244.815	244.815	.000	1.9696	1.8609	.9448	
T62B	245/2E	9/20/68	244.588	244.619	.031	1.9232	1.8158	.9442	
T69A0	245/2	10/28/68	244.447	244.462	.015	1.9972	1.8947	.9487	
T69A1	245/2	10/30/68	245.127	245.125	-.002	2.0651	1.9550	.9467	
T69A2	245/2	10/31/68	245.117	245.122	.006	2.0695	1.9598	.9470	
T69A3	245/2	11/ 1/68	245.097	245.115	.018	2.0699	1.9601	.9470	
T57B	225/18E	5/ 2/68	234.100	234.319	.219-.2=.02	17.3685	16.4356	.9463	
T65A	225/18E	10/ 2/68	233.909	234.161	.25-.20=.05	17.3226	16.2912	.9405	
T69B	225/18	11/ 4/68	234.287	234.548	.261-.2=.061	17.3837	16.4247	.9448	
								ΔT OFFSET (Zero ΔT Tests)	

* E designates tests run with probe electronics.

36-10

Arthur D. Little, Inc.

PROBE HALF F2-1

S/N 2227

RING BRIDGE (UPPER)

OTHER DATA (UNOFFICIAL)

HEAT FLOW PROBE PROGRAM

Bendix Contract SC 0242

Case 68647 5

TEST DATA SUMMARY

NOTE: Ring data include offset corrections.

ΔT OFFSET = .0224°K
T OFFSET = .40°K

36-11

1 TEST NO.	2 NOMINAL CONDITIONS T/DT*	3 DATE	4 TA 01 (°K)	5 T 11 (°K)	6 5 - 4 ERROR T	7 DTA 01 (°K)	8 DT R11 (°K)	9 8 / 7	10 DEVIATION FROM "BEST LINE" (°K)
T57A	245/2E	5/ 1/68	242.731	242.725	-.006	2.0946	1.2125	.5786	
T61A	245/2E	9/11/68	242.773	242.752	-.021	2.0799	1.2041	.5788	
T62A	245/2E	9/16/68	242.494	242.459	-.035	2.0013	1.1586	.5787	
T62B	245/2E	9/20/68	242.337	242.302	-.035	1.9523	1.1301	.5788	
T69A2	245/2	10/31/68	242.711	242.665	-.046	2.0889	1.2106	.5795	
T69A1	245/2	10/30/68	242.700	242.648	-.052	2.0985	1.2166	.5767	
T69A3	245/2	11/ 1/68	242.681	242.642	-.039	2.0987	1.2164	.5795	
T67A	205/-2E	10/17/68	205.512	205.515	.002	-2.1235	-1.2030	.5665	
T69B	225/18	11/ 4/68	213.932	214.002	.071	17.749	10.132	.5708	

ΔT OFFSET (Zero ΔT Tests)

* E designates tests run with probe electronics.

Arthur D. Little, Inc.

PROBE HALF F2-1

S/N 2223

RING BRIDGE (Lower)

OTHER DATA (UNOFFICIAL)

HEAT FLOW PROBE PROGRAM

Bendix Contract SC 0242

Case 68647 5

TEST DATA SUMMARY

NOTE: Ring data include offset corrections.

ΔT OFFSET = .0118°K

T OFFSET = .43°K

1 TEST NO.	2 NOMINAL CONDITIONS T/DT*	3 DATE	4 TA 02 (°K)	5 T R12 (°K)	6 5 - 4 ERROR T	7 DTA 02 (°K)	8 DT R12 (°K)	9 8 / 7	10 DEVIATION FROM "BEST LINE" (°K)
T57A	245/2E	5/ 1/68	245.141	245.141	.00	2.0659	1.1994	.5808	
T61A	245/2E	9/11/68	245.176	245.059	.117	2.0536	1.1933	.5814	
T62A	245/2E	9/16/68	244.806	244.809	.003	1.9664	1.1430	.5814	
T62B	245/2E	9/20/68	244.590	244.578	-.012	1.9233	1.1174	.5810	
T69A1	245/2	10/30/68	245.127	245.111	-.016	2.0651	1.2010	.5815	
T69A2	245/2	10/31/68	245.117	245.105	-.012	2.0695	1.2033	.5811	
T69A3	245/2	11/ 1/68	245.097	245.103	.006	2.0699	1.2036	.5814	
T67A	205/-2E	10/17/68	203.034	203.032	-.002	-2.1710	-1.2333	.5680	
T69B	225/18	11/4/68	234.287	234.595	.308 -.2 = .108	17.3837	10.0529	.5782	

ΔT OFFSET (Zero ΔT Tests)

36-12

* E designates tests run with probe electronics.

Arthur D. Little, Inc.

PROBE HALF F2-2

S/N 2230

GRADIENT BRIDGE (UPPER)

OTHER DATA (UNOFFICIAL)

HEAT FLOW PROBE PROGRAM

Bendix Contract SC 0242

Case 68647 5

NOTE: Ring data include offset corrections.

TEST DATA SUMMARY

1 TEST NO.	2 NOMINAL CONDITIONS T/DT*	3 DATE	4 TA 01 (°K)	5 T G21 (°K)	6 5 - 4 ERROR T	7 DTA 01 (°K)	8 DT G21 (°K)	9 8 / 7	10 DEVIATION FROM "BEST LINE" (°K)
T58B	245/2E	5/6/68	242.669	242.639	-.030	2.1050	2.0052	.9526	
T66B	245/2E	10/7/68	242.492	242.502	.010	2.0770	1.9795	.9531	
T58A	225/18E	5/4/68	213.797	213.809	.012	17.7290	16.7535	.9450	
T66A	225/18E	10/3/68	213.663	213.678	.015	17.6746	16.7167	.9458	
								ΔT OFFSET (Zero ΔT Tests)	

* E designates tests run with probe electronics.

36-13

Arthur D. Little, Inc.

PROBE HALF F2-2

S/N 2226

GRADIENT BRIDGE (LOWER)

OTHER DATA (UNOFFICIAL)

HEAT FLOW PROBE PROGRAM

Bondix Contract SC 0242

Case 68647 5

NOTE: Ring data include offset corrections.

TEST DATA SUMMARY

1 TEST NO.	2 NOMINAL CONDITIONS T/DT*	3 DATE	4 TA 02 (°K)	5 T G22 (°K)	6 5 - 4 ERROR T	7 DTA 02 (°K)	8 DT G22 (°K)	9 8 / 7	10 DEVIATION FROM "BEST LINE" (°K)
T58B	245/2E	5/6/68	245.099	245.072	-.028	2.0759	1.9693	.9486	
T66B	245/2E	10/7/68	244.894	244.890	-.004	2.0473	1.9421	.9486	
T66A	225/18E	10/3/68	233.915	234.102	.187-.20 =-.013	17.2979	16.3813	.9470	
T58A	225/18E	5/4/68	234.120	234.326	.205 -.20 =.005	17.3609	16.4521	.9477	

ΔT OFFSET (Zero ΔT Tests)

* E designates tests run with probe electronics.

36-14

Arthur D. Little, Inc.

PROBE HALF F2-2

S/N 2230

RING BRIDGE (UPPER)

OTHER DATA (UNOFFICIAL)

HEAT FLOW PROBE PROGRAM

Bendix Contract SC 0242

Case 68647 5

TEST DATA SUMMARY

NOTE: Ring data include offset corrections.
ΔT OFFSET = -.080°K
T OFFSET = .43°K

1 TEST NO.	2 NOMINAL CONDITIONS T/DT*	3 DATE	4 TA 01 (°K)	5 T R21 (°K)	6 5 - 4 ERROR T	7 DTA 01 (°K)	8 DT R21 (°K)	9 8 / 7	10 DEVIATION FROM "BEST LINE" (°K)
T58B	245/2E	5/6/68	242.668	242.682	-.014	2.1053	1.2219	.5804	
T66B	245/2E	10/7/68	242.490	242.506	.016	2.0770	1.2041	.5797	
									ΔT OFFSET (Zero ΔT Tests)

* E designates tests run with probe electronics.

36-15

Arthur D. Little, Inc.

PROBE HALF F2-2

S/N 2226

RING BRIDGE (LOWER)

OTHER DATA (UNOFFICIAL)

HEAT FLOW PROBE PROGRAM

Bendix Contract SC 0242

Case 63647 5

TEST DATA SUMMARY

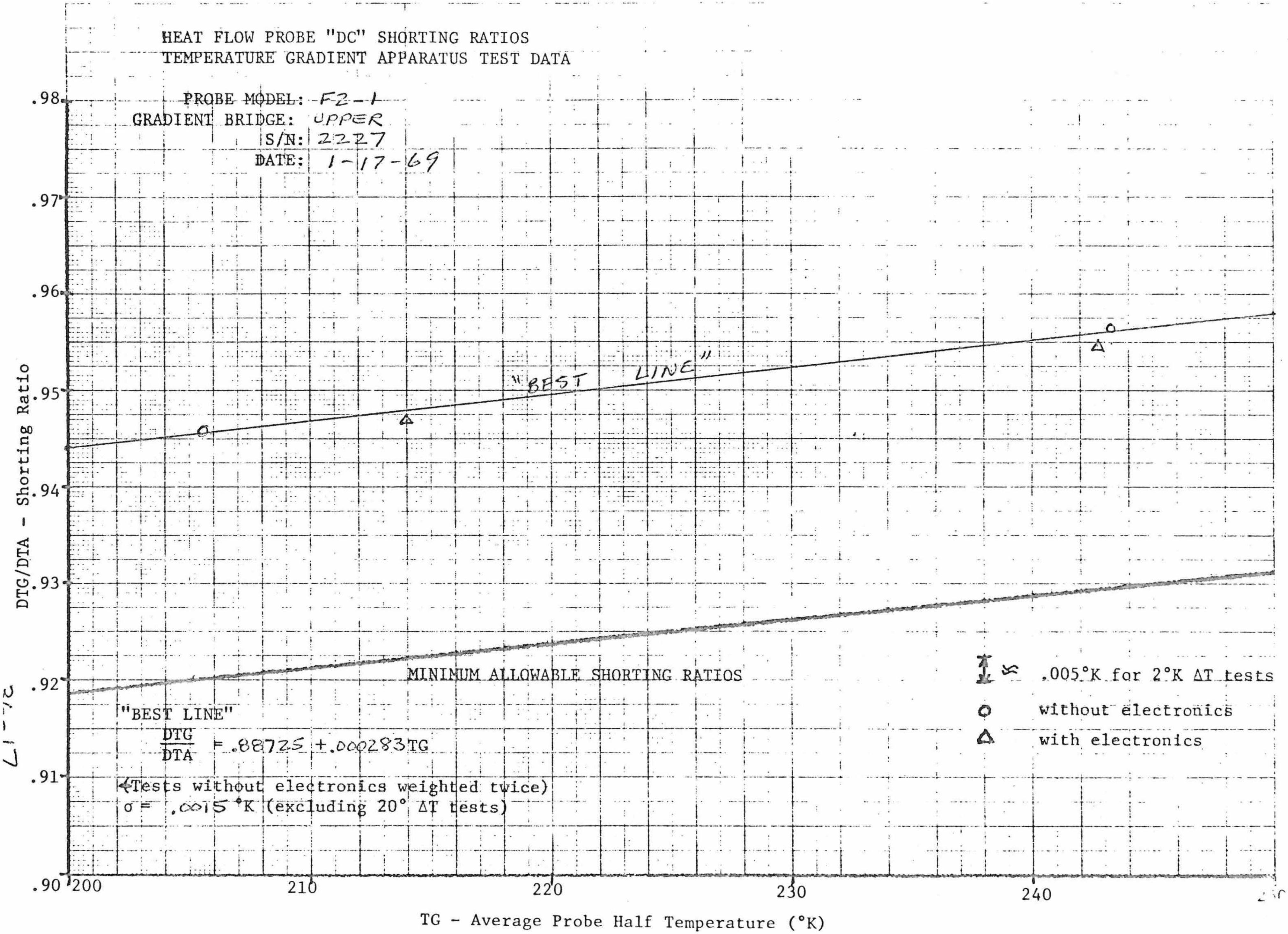
NOTE: Ring data include offset corrections.
ΔT OFFSET = -.0113°K
T OFFSET = .42°K

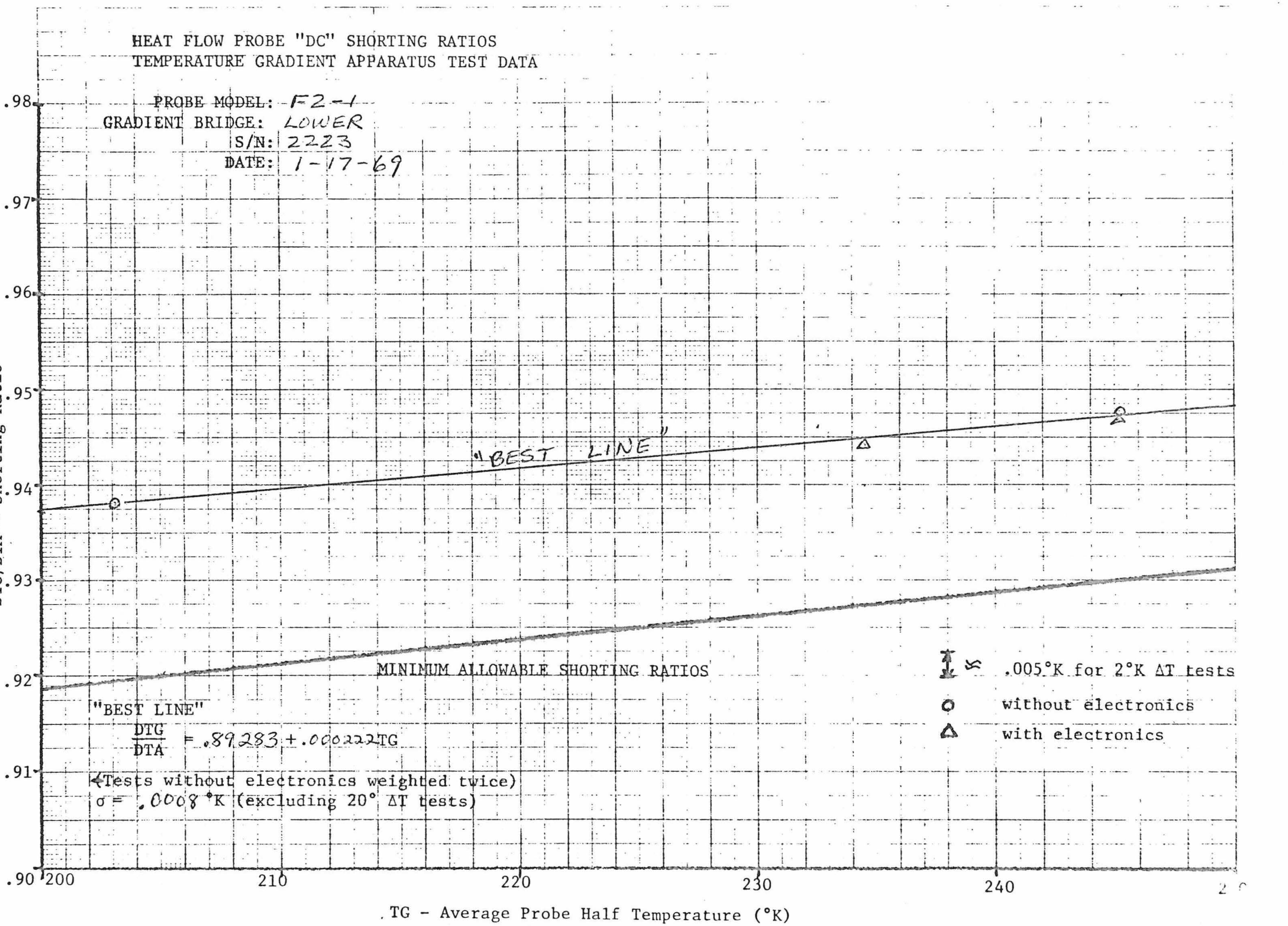
1 TEST NO.	2 NOMINAL CONDITIONS T/DT*	3 DATE	4 TA 02 (°K)	5 T R22 (°K)	6 5 - 4 ERROR T	7 DTA 02 (°K)	8 DT R22 (°K)	9 8 / 7	10 DEVIATION FROM "BEST LINE" (°K)
T58B	245/2E	5/6/68	245.101	245.101	.000	2.0758	1.2037	.5799	
T66A	245/2E	10/7/68	244.893	244.931	.038	2.0473	1.1859	.5793	

ΔT OFFSET
(Zero ΔT Tests)

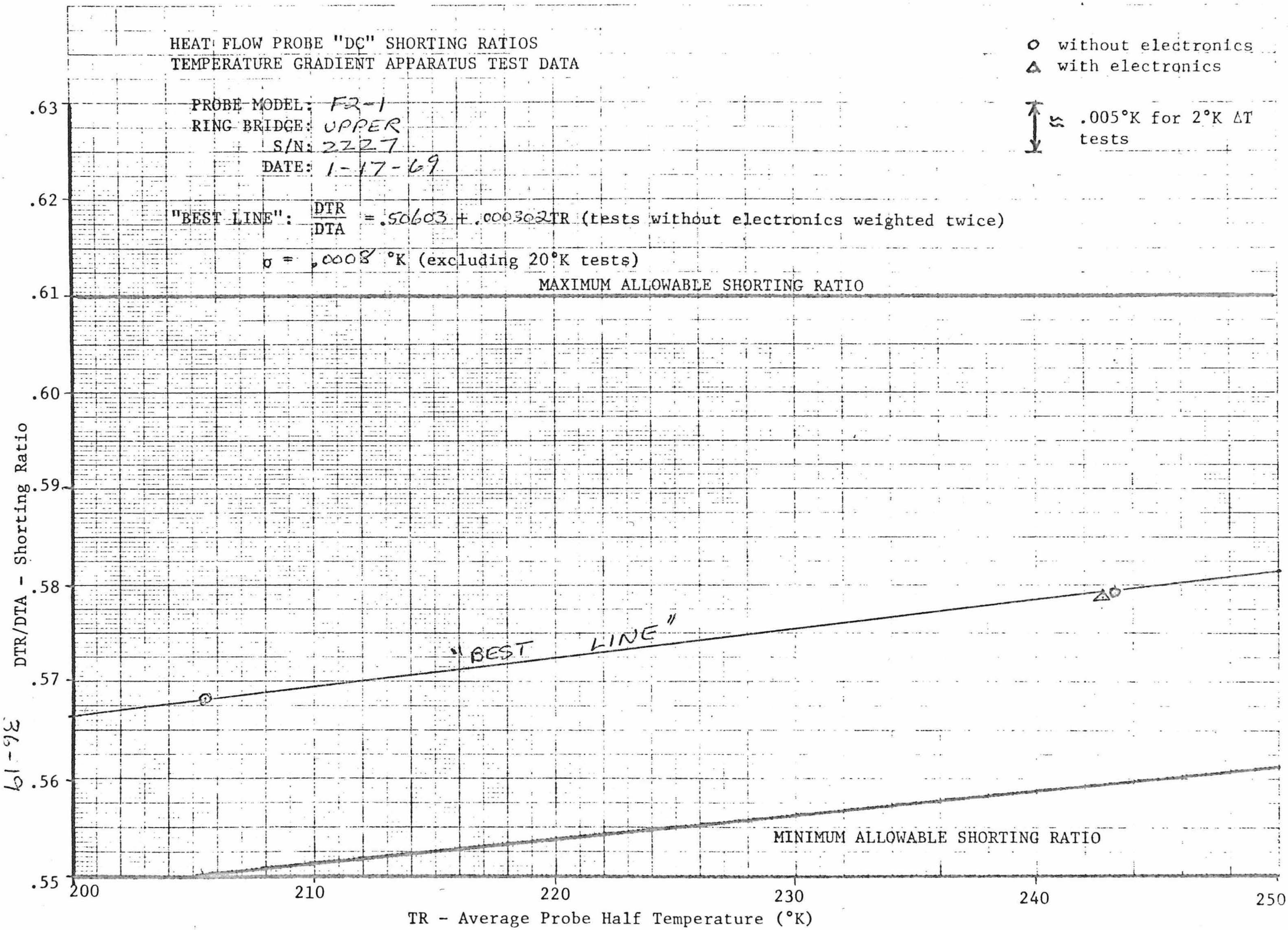
* E designates tests run with probe electronics.

36-16


HEAT FLOW PROBE "DC" SHORTING RATIOS
TEMPERATURE GRADIENT APPARATUS TEST DATA
PROBE MODEL: F2-1
GRADIENT BRIDGE: UPPER
S/N: 2227
DATE: 1-17-69
"BEST LINE"
MINIMUM ALLOWABLE SHORTING RATIOS
≈ .005°K for 2°K ΔT tests
without electronics
with electronics
"BEST LINE"
DTG/DTA = .88725 + .000283TG
(Tests without electronics weighted twice)
σ = .0015 °K (excluding 20° ΔT tests)
DTG/DTA - Shorting Ratio
.98
.97
.96
.95
.94
.93
.92
.91
.90
200
210
220
230
240
250
TG - Average Probe Half Temperature (°K)

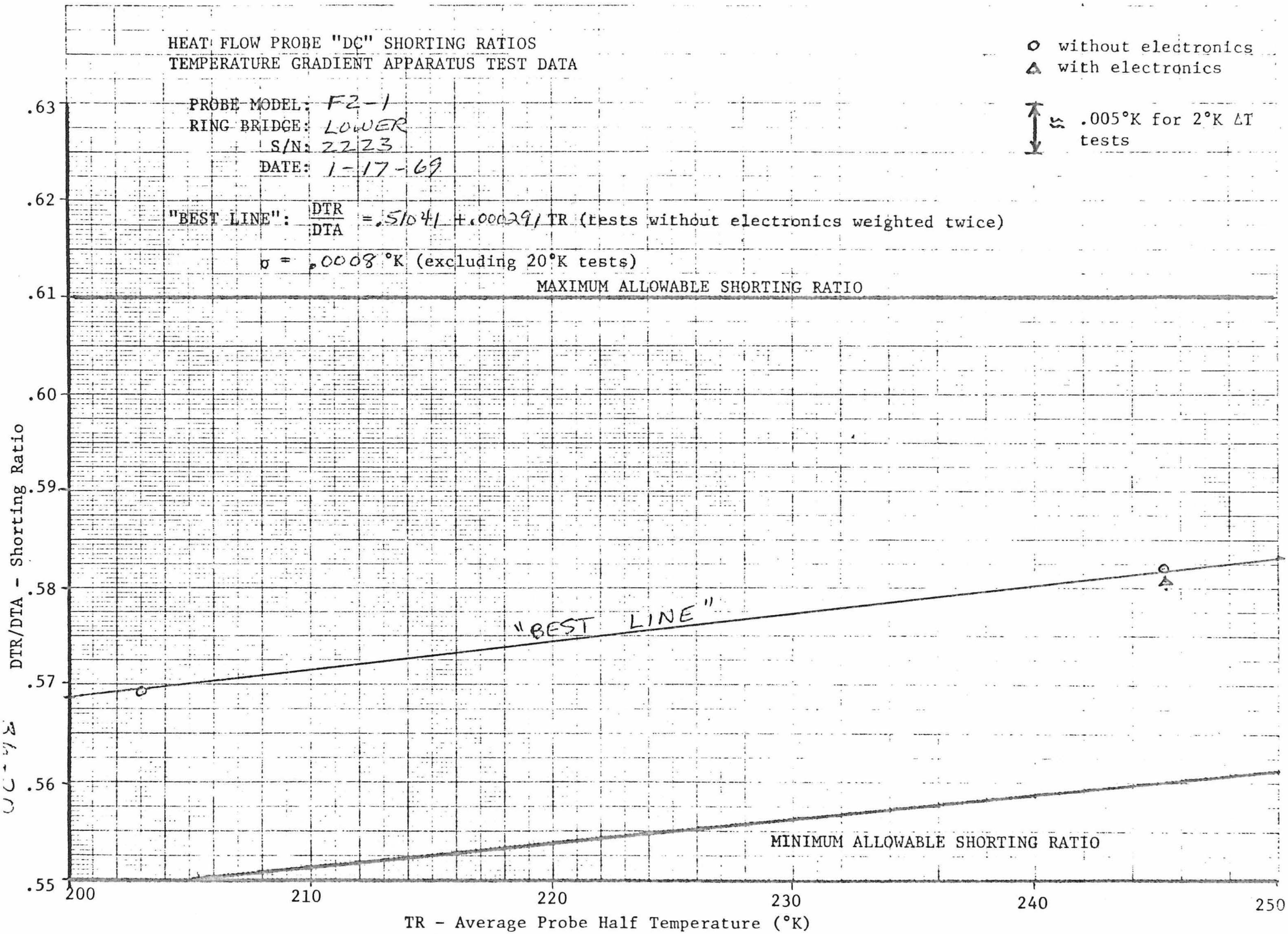

HEAT FLOW PROBE "DC" SHORTING RATIOS
TEMPERATURE GRADIENT APPARATUS TEST DATA
PROBE MODEL: F2-1
GRADIENT BRIDGE: LOWER
S/N: 2223
DATE: 1-17-69
.98
.97
.96
.95
.94
.93
.92
.91
.90
DTG/DTA - Shorting Ratio
"BEST LINE"
MINIMUM ALLOWABLE SHORTING RATIOS
"BEST LINE"
DTG/DTA = .89283 + .000222TG
(Tests without electronics weighted twice)
σ = .0008 °K (excluding 20° ΔT tests)
≈ .005°K for 2°K ΔT tests
without electronics
with electronics
200
210
220
230
240
TG - Average Probe Half Temperature (°K)

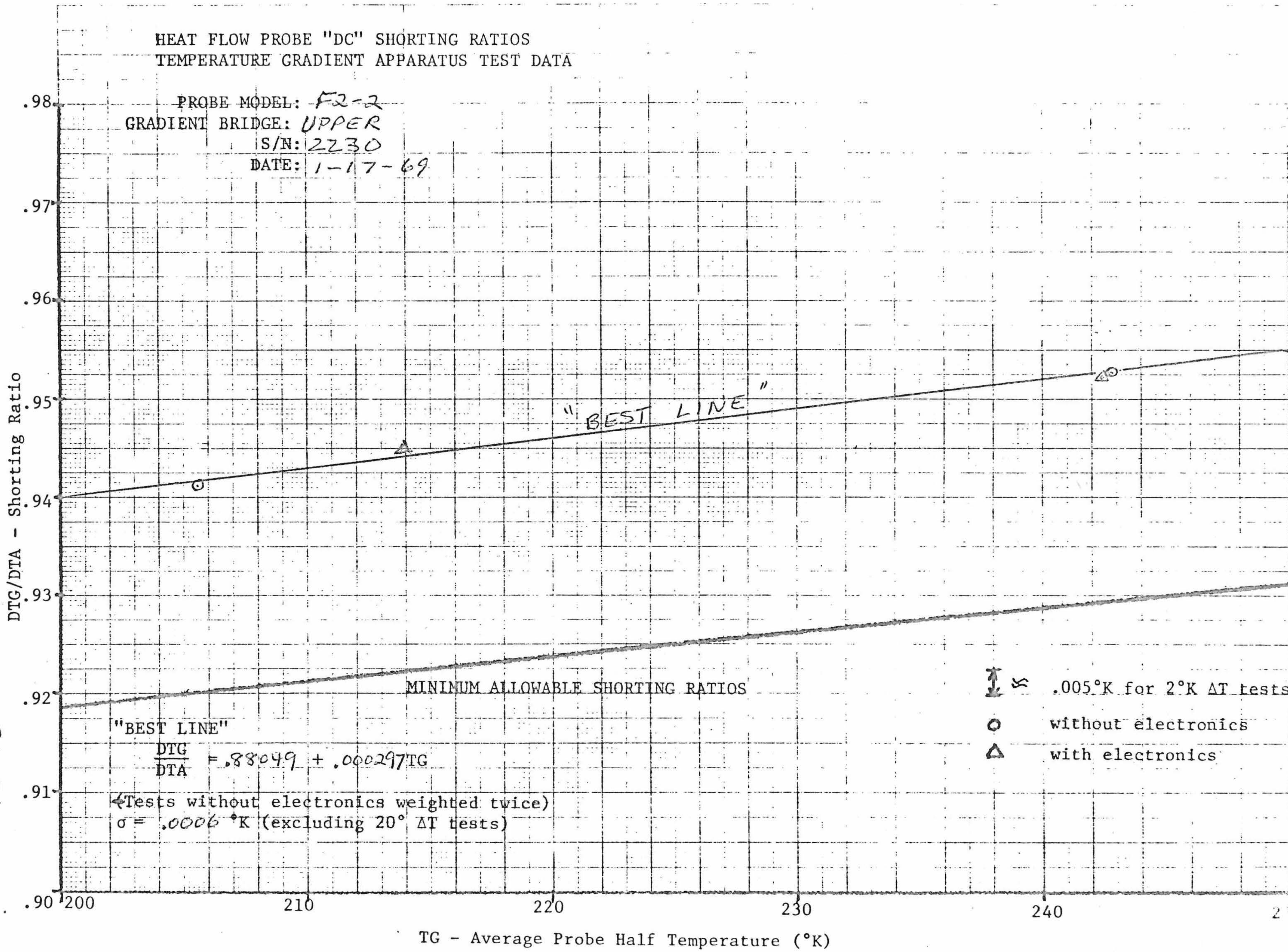
3-42

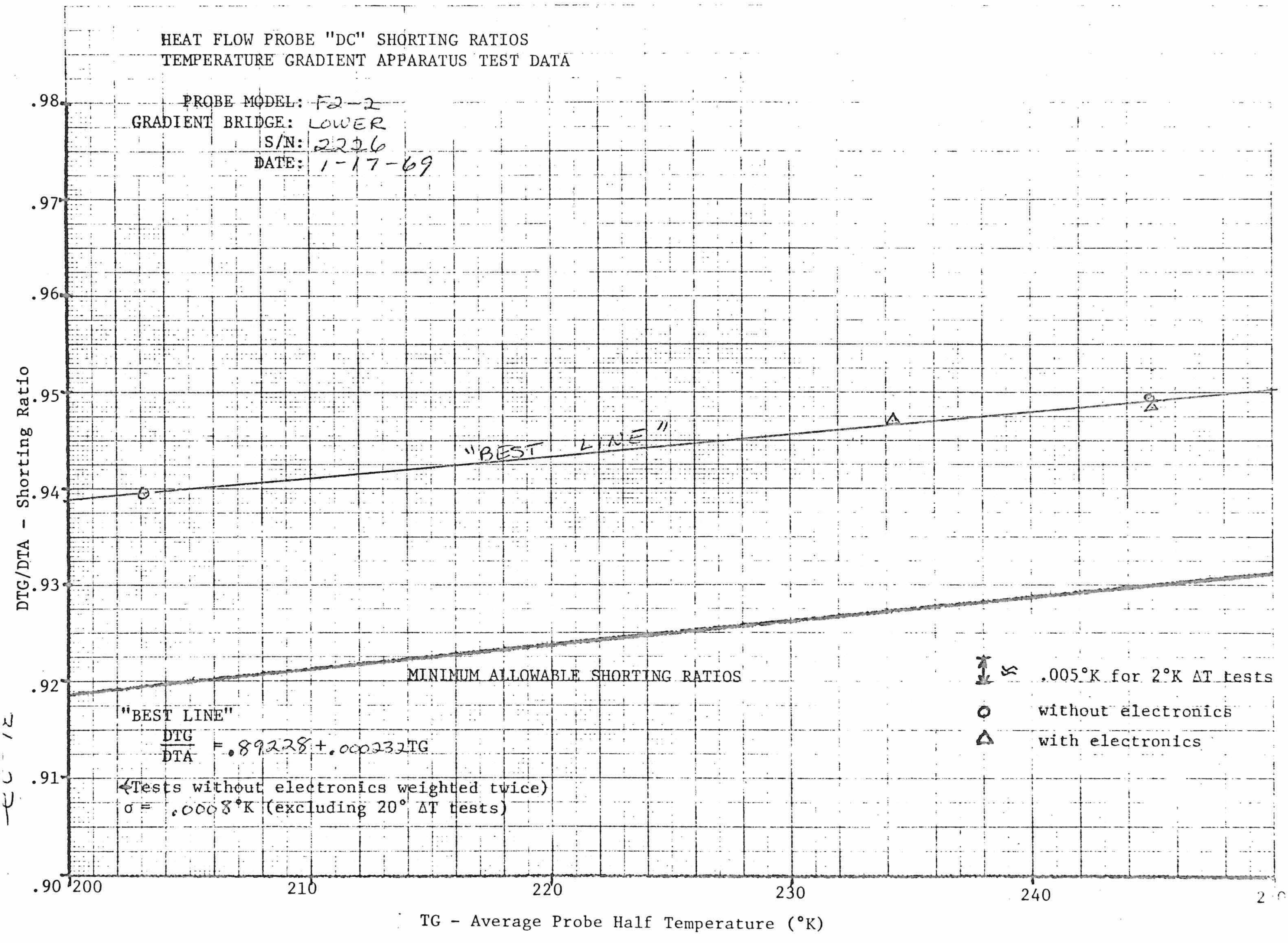


HEAT FLOW PROBE "DC" SHORTING RATIOS
TEMPERATURE GRADIENT APPARATUS TEST DATA
PROBE MODEL: F2-1
RING BRIDGE: UPPER
S/N: 2227
DATE: 1-17-69
"BEST LINE": DTR/DTA = .50603 + .000302TR (tests without electronics weighted twice)
σ = .0008 °K (excluding 20°K tests)
o without electronics
Δ with electronics
≈ .005°K for 2°K ΔT tests
MAXIMUM ALLOWABLE SHORTING RATIO
MINIMUM ALLOWABLE SHORTING RATIO
"BEST LINE"
DTR/DTA - Shorting Ratio
TR - Average Probe Half Temperature (°K)
.63
.62
.61
.60
.59
.58
.57
.56
.55
200
210
220
230
240
250

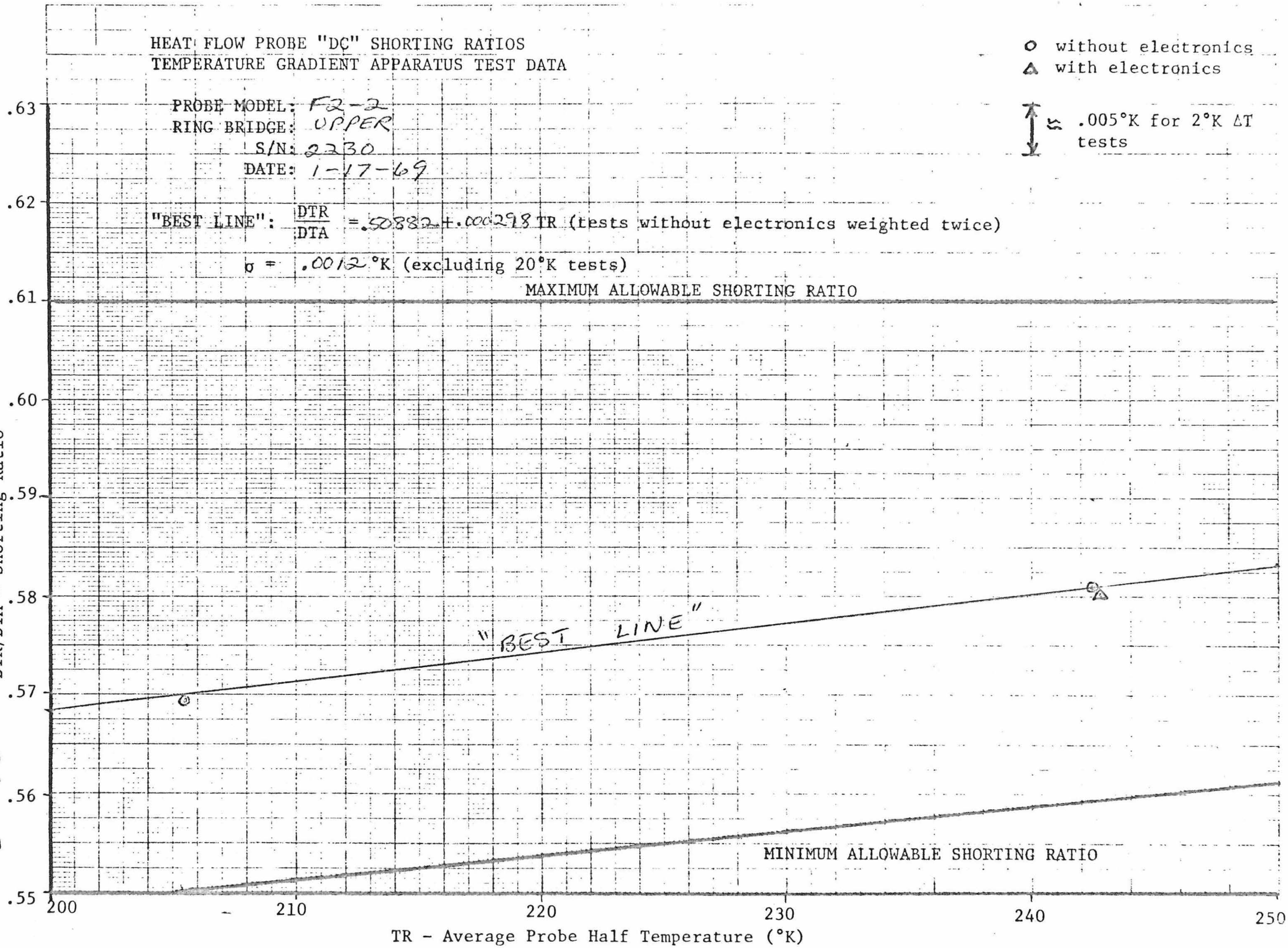
36-19


HEAT FLOW PROBE "DC" SHORTING RATIOS
TEMPERATURE GRADIENT APPARATUS TEST DATA
PROBE MODEL: F2-1
RING BRIDGE: LOWER
S/N: 2223
DATE: 1-17-69
"BEST LINE": DTR/DTA = .51041 + .000291 TR (tests without electronics weighted twice)
σ = .0008 °K (excluding 20°K tests)
o without electronics
△ with electronics
≈ .005°K for 2°K ΔT tests
MAXIMUM ALLOWABLE SHORTING RATIO
"BEST LINE"
MINIMUM ALLOWABLE SHORTING RATIO
.63
.62
.61
.60
.59
.58
.57
.56
.55
DTR/DTA - Shorting Ratio
200
210
220
230
240
250
TR - Average Probe Half Temperature (°K)

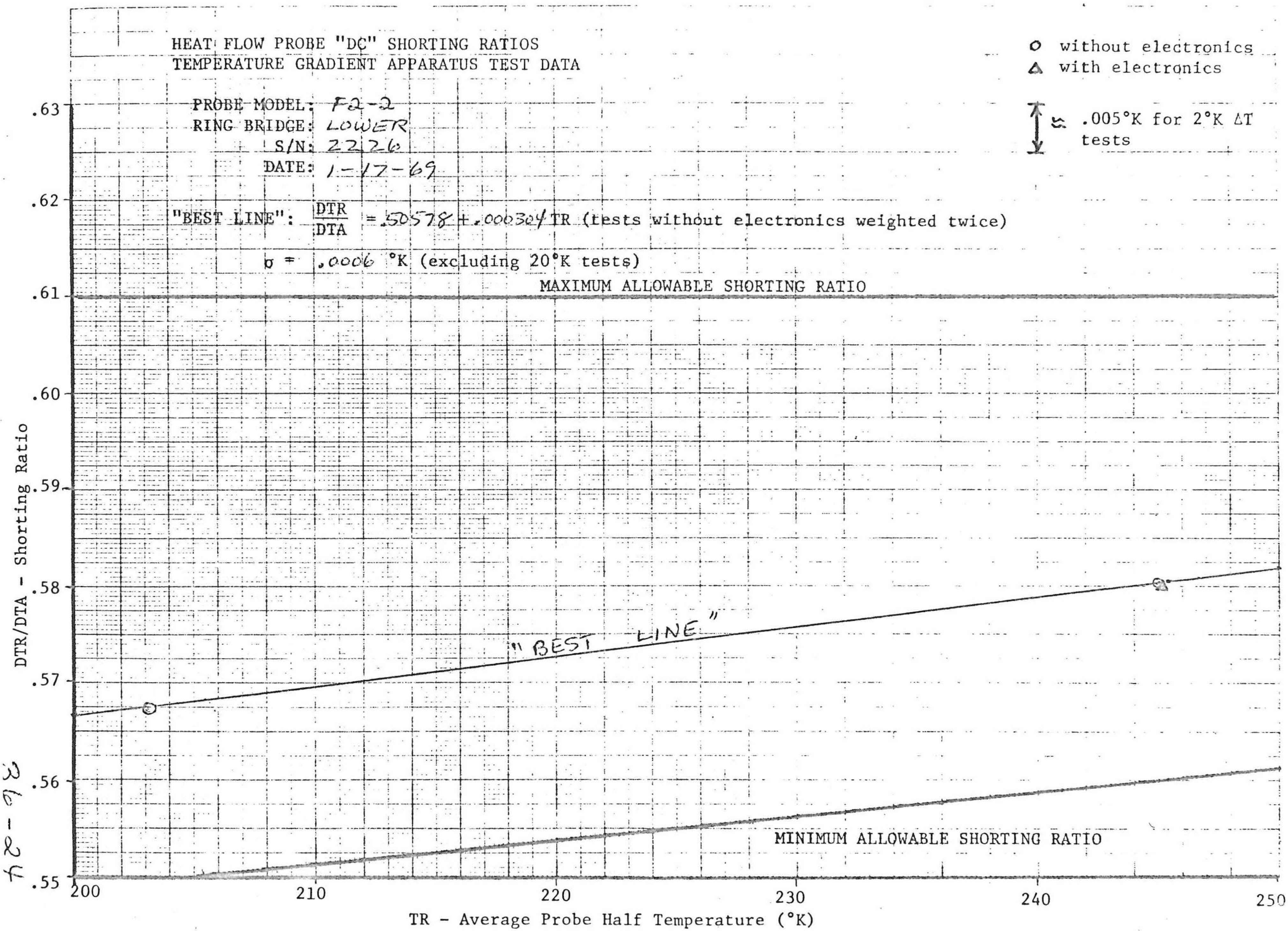

HEAT FLOW PROBE "DC" SHORTING RATIOS
TEMPERATURE GRADIENT APPARATUS TEST DATA
PROBE MODEL: F2-2
GRADIENT BRIDGE: UPPER
S/N: 2230
DATE: 1-17-69
"BEST LINE"
MINIMUM ALLOWABLE SHORTING RATIOS
"BEST LINE"
DTG/DTA = .88049 + .000297TG
(Tests without electronics weighted twice)
σ = .0006 °K (excluding 20° ΔT tests)
≈ .005°K for 2°K ΔT tests
without electronics
with electronics
DTG/DTA - Shorting Ratio
.98
.97
.96
.95
.94
.93
.92
.91
.90
200
210
220
230
240
TG - Average Probe Half Temperature (°K)



HEAT FLOW PROBE "DC" SHORTING RATIOS
TEMPERATURE GRADIENT APPARATUS TEST DATA
PROBE MODEL: F2-2
GRADIENT BRIDGE: LOWER
S/N: 2226
DATE: 1-17-69
"BEST LINE"
MINIMUM ALLOWABLE SHORTING RATIOS
≈ .005°K for 2°K ΔT tests
without electronics
with electronics
"BEST LINE"
DTG/DTA = .89228 + .000232TG
(Tests without electronics weighted twice)
σ = .0008°K (excluding 20° ΔT tests)
.98
.97
.96
.95
.94
.93
.92
.91
.90
DTG/DTA - Shorting Ratio
200
210
220
230
240
TG - Average Probe Half Temperature (°K)


HEAT FLOW PROBE "DC" SHORTING RATIOS
TEMPERATURE GRADIENT APPARATUS TEST DATA
o without electronics
△ with electronics
≅ .005°K for 2°K ΔT tests
PROBE MODEL: F2-2
RING BRIDGE: UPPER
S/N: 2230
DATE: 1-17-69
"BEST LINE": DTR/DTA = .50882 + .000298 TR (tests without electronics weighted twice)
σ = .0012°K (excluding 20°K tests)
MAXIMUM ALLOWABLE SHORTING RATIO
"BEST LINE"
MINIMUM ALLOWABLE SHORTING RATIO
.63
.62
.61
.60
.59
.58
.57
.56
.55
DTR/DTA - Shorting Ratio
200
210
220
230
240
250
TR - Average Probe Half Temperature (°K)

36-23


HEAT FLOW PROBE "DC" SHORTING RATIOS
TEMPERATURE GRADIENT APPARATUS TEST DATA
PROBE MODEL: F2-2
RING BRIDGE: LOWER
S/N: 2226
DATE: 1-17-69
"BEST LINE": DTR/DTA = .50578 + .000304 TR (tests without electronics weighted twice)
σ = .0006 °K (excluding 20°K tests)
o without electronics
△ with electronics
≈ .005°K for 2°K ΔT tests
MAXIMUM ALLOWABLE SHORTING RATIO
"BEST LINE"
MINIMUM ALLOWABLE SHORTING RATIO
.63
.62
.61
.60
.59
.58
.57
.56
.55
DTR/DTA - Shorting Ratio
200
210
220
230
240
250
TR - Average Probe Half Temperature (°K)

Arthur D. Little, Inc.

HEAT FLOW PROBE PROGRAM

Bendix Contract SC 0242

Case 68647 5

Thermocouple Performance Summary Sheet

Probe Models: F2-1 and F2-2

ATP 0501, Part IV, Rev. D

1. Comparison during ΔT Tests with Electronics between temperature measured by bottom thermocouple (TC) and temperature of upper gradient sensor per Paragraph 3.5.5

Test Number	Probe	No. Data Points	Average TC Temp. (°K)	$\pm\sigma$ TC Temperature (°K)	Probe Upper Gradient Sensor (°K) Temperature	Probe Sensor Temp.-TC Temp. (°K)
T73A	F2-1	15	242.11	± .30	241.81	-.30
T73B	F2-1	15	205.64	± .21	205.61	-.03
T74A	F2-2	15	205.59	± .17	205.56	-.03
T74B	F2-2	15	242.06	± .24	241.72	-.34

2. Comparison between thermocouple temperatures during test in isothermal sleeve (per paragraph 5.5)

Probe	No. Data Points	Average Temperature ± Standard Deviation			
		Bottom TC	Next-to-Bottom TC	Next-to-Top TC	Top TC
F2-1	15	297.30 ± .12	296.94 ± .12	296.84 ± .14	296.48 ± .13
F2-2	15	297.70 ± .11	297.33 ± .12	297.26 ± .12	296.91 ± .13

36-25

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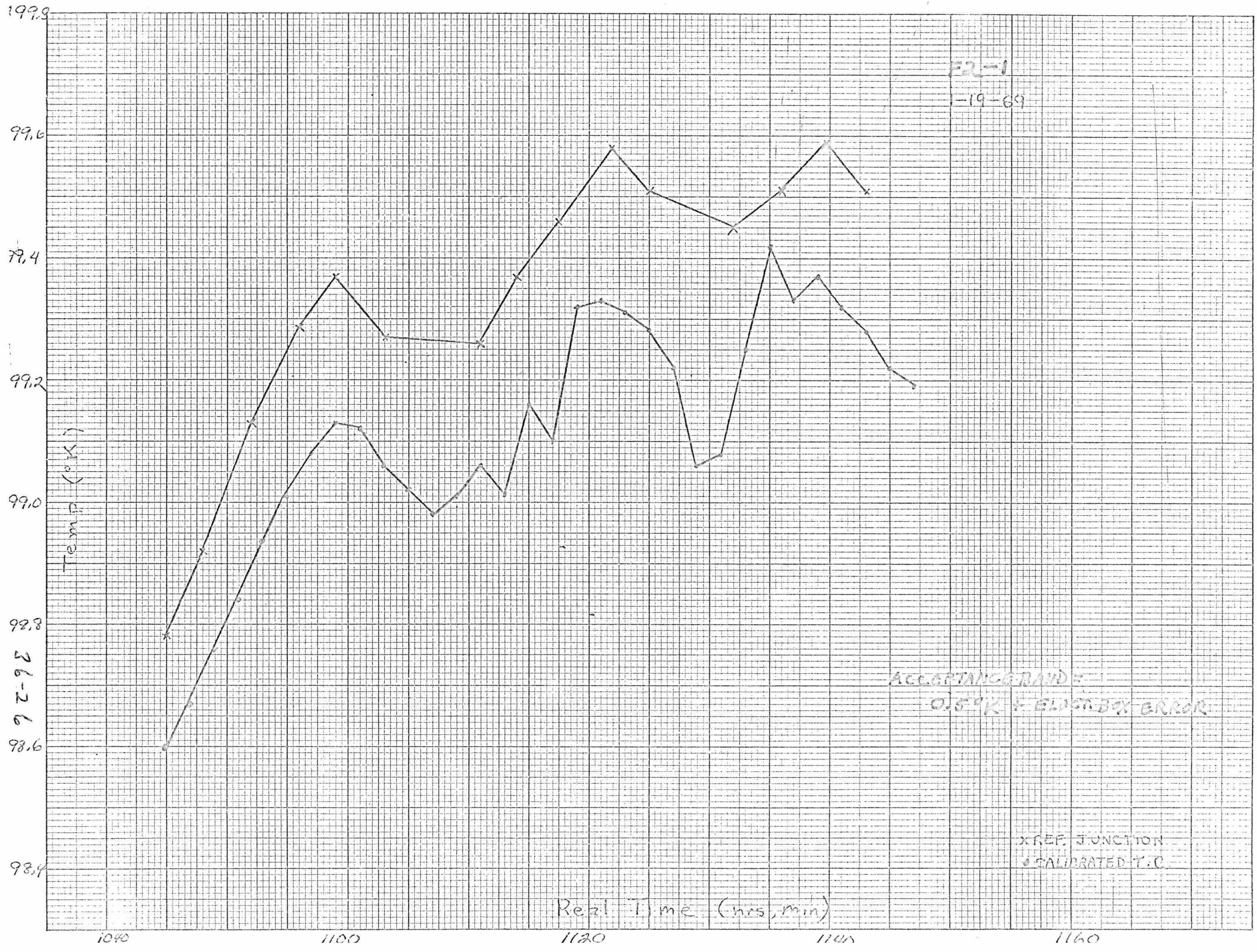

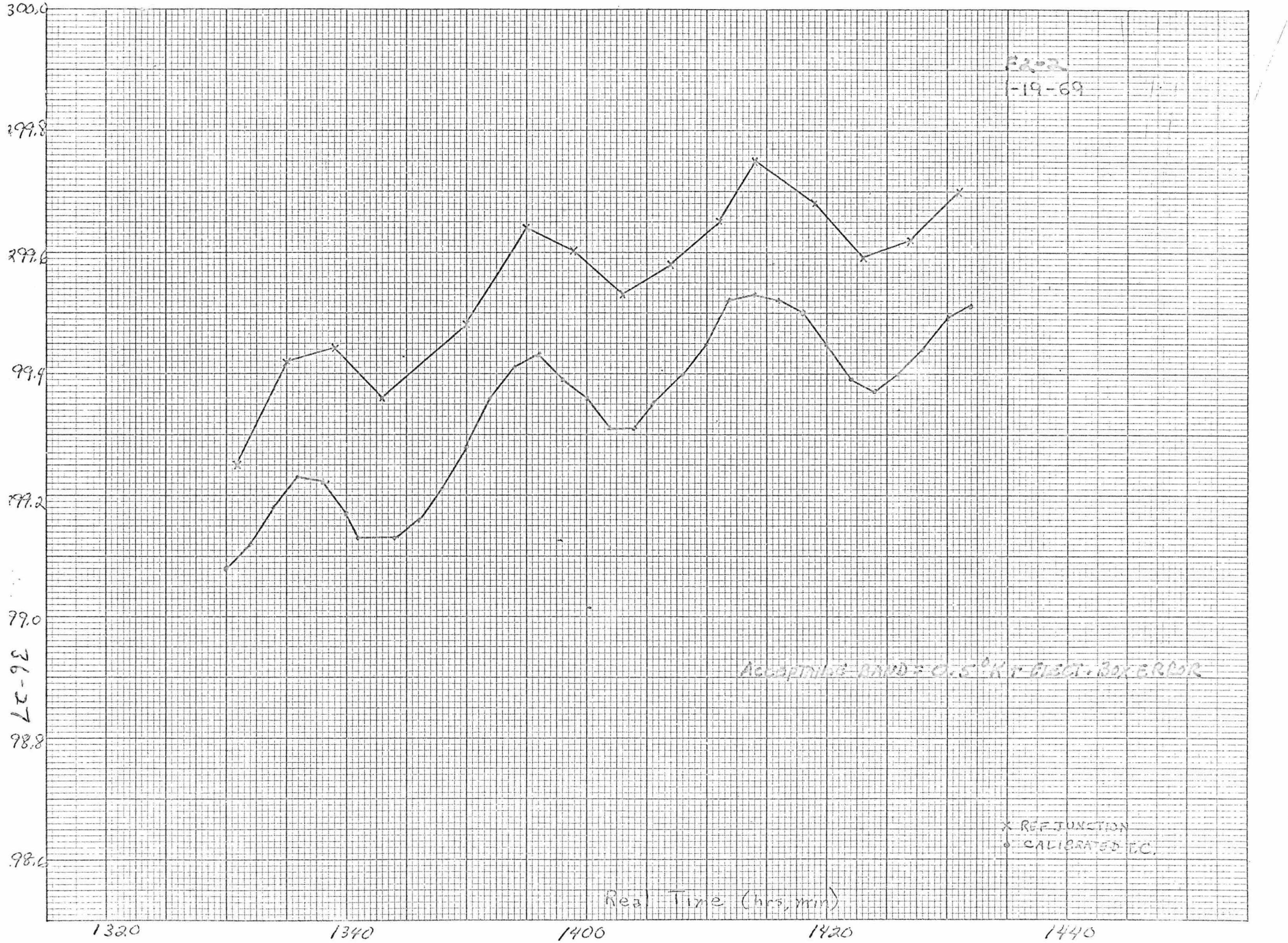
F2-2
1-19-69
ACCEPTANCE BAND = 0.5°K + ELECT. BOX ERROR
X REF JUNCTION
o CALIBRATED T.C.
300.0
299.8
299.6
99.4
99.2
99.0
98.8
98.6
Real Time (hrs, min)
1320
1340
1400
1420
1440

36-37

Arthur D. Little, Inc.

HEAT FLOW PROBE PROGRAM

Bendix Contract SC 0242

Case 68647 5

PERFORMANCE CRITERIA

PROBE HALF F2-1 UPPER

S/N 2227

GRADIENT BRIDGE

DATE 1-17-69

(Comparison between ADL ΔT apparatus gradient tube instrumentation and probe.)

AVG. ABSOLUTE TEMPERATURE

	Standard deviation			No. Data Pts.
All data	σ	=	.03 °K	5

TEMPERATURE DIFFERENCE

Equation of "best line" through shorting ratio data

$$\frac{DTG}{DTA} = .88725 + .000283\ TG$$

Standard deviation from "best line" — No. Data Pts.

(excluding 20° ΔT tests) σ= .0015 °K — 4

EQUIVALENT MEASURING LENGTH

(all data except for tests near zero ΔT)

2X = 17.958 in. ± .037 in.

$$\frac{\text{Equivalent Length}}{\text{Centerline Separation of Sensors}} = .9638 \pm .0020$$

Arthur D. Little, Inc.

HEAT FLOW PROBE PROGRAM

Bendix Contract SC 0242

Case 68647 5

PERFORMANCE CRITERIA

PROBE HALF F2-1 LOWER

S/N 2223

GRADIENT BRIDGE

DATE 1-17-69

(Comparison between ADL ΔT apparatus gradient tube instrumentation and probe.)

AVG. ABSOLUTE TEMPERATURE

			No. Data Pts.
Standard deviation			
All data σ	=	.04 °K	5

TEMPERATURE DIFFERENCE

Equation of "best line" through shorting ratio data

$$\frac{DTG}{DTA} = .89283 + .000222\ TG$$

Standard deviation from "best line" — No. Data Pts.

(excluding 20° ΔT tests) σ= .0008 °K — 4

EQUIVALENT MEASURING LENGTH

(all data except for tests near zero ΔT)

2X = 17.736 in. ± .034 in.

$$\frac{\text{Equivalent Length}}{\text{Centerline Separation of Sensors}} = .9520 \pm .0018$$

HEAT FLOW PROBE PROGRAM

Bendix Contract SC 0242

Case 68647 5

PERFORMANCE CRITERIA

PROBE HALF F2-1 UPPER

S/N 2227

RING BRIDGE

DATE 1-17-69

AVG. ABSOLUTE TEMPERATURE

EXP. OFFSET. ΔR_B = -.80 Ω (- .40 °K)
(From ADL ΔT Apparatus test data)

Following offset correction:

Standard Deviation

All data σ = .015 °K

TEMPERATURE DIFFERENCE

EXP. OFFSET = .0224 °K ± N.A. °K
(From near zero ΔT tests)

Following offset correction:

Equation of "best line" through shorting ratio data

$$\frac{DTR}{DTA} = .50603 + .000302\ TR$$

Standard deviation from "best line"

(excluding 20°ΔT data) σ = .0008 °K No. of points 3

LENGTH RATIO (All tests except for those near zero ΔT)

At 225°K

$$\text{Length Ratio} = \frac{\text{Centerline Separation of Sensors}}{\text{Centerline Separation of GT Thermopiles}} = \frac{11.2976}{18.684} = .60467$$

$$\text{Shorting Ratio} = \frac{\text{"Best Line" Ratio at 225°K}}{\text{Length Ratio}} = .9491$$

HEAT FLOW PROBE PROGRAM

Bendix Contract SC 0242

Case 68647 5

PERFORMANCE CRITERIA

PROBE HALF F2-1 LOWER

S/N 2223

RING BRIDGE

DATE 1-17-69

AVG. ABSOLUTE TEMPERATURE

EXP. OFFSET. ΔR_B = -.86 Ω (- .43 °K)
(From ADL ΔT Apparatus test data)

Following offset correction:

Standard Deviation

All data σ = .035 °K

TEMPERATURE DIFFERENCE

EXP. OFFSET = .0118 °K ± N.A. °K
(From near zero ΔT tests)

Following offset correction:

Equation of "best line" through shorting ratio data

$$\frac{DTR}{DTA} = .51041 + .000291 \text{ TR}$$

Standard deviation from "best line"

(excluding 20°ΔT data) σ = .0008 °K   No. of points 3

LENGTH RATIO (All tests except for those near zero ΔT)

At 225°K

$$\text{Length Ratio} = \frac{\text{Centerline Separation of Sensors}}{\text{Centerline Separation of GT Thermopiles}} = \frac{11.2926}{18.684} = .6044$$

$$\text{Shorting Ratio} = \frac{\text{"Best Line" Ratio at 225°K}}{\text{Length Ratio}} = .9527$$

HEAT FLOW PROBE PROGRAM

Bendix Contract SC 0242

Case 68647 5

PERFORMANCE CRITERIA

PROBE HALF F2-2 UPPER

S/N 2230

GRADIENT BRIDGE

DATE 1-17-69

(Comparison between ADL ΔT apparatus gradient tube instrumentation and probe.)

AVG. ABSOLUTE TEMPERATURE

		No. Data Pts.
Standard deviation		
All data σ =	.03 °K	5

TEMPERATURE DIFFERENCE

Equation of "best line" through shorting ratio data

$$\frac{DTG}{DTA} = .88049 + .000297\ TG$$

		No. Data Pts.
Standard deviation from "best line"		
(excluding 20° ΔT tests) σ=	.0006 °K	4

EQUIVALENT MEASURING LENGTH

(all data except for tests near zero ΔT)

2X = 17.843 in. ± .071 in.

$$\frac{\text{Equivalent Length}}{\text{Centerline Separation of Sensors}} = .9580 \pm .0038$$

HEAT FLOW PROBE PROGRAM

Bendix Contract SC 0242

Case 68647 5

PERFORMANCE CRITERIA

PROBE HALF F2-2 LOWER

S/N 2226

GRADIENT BRIDGE

DATE 1-17-69

(Comparison between ADL ΔT apparatus gradient tube instrumentation and probe.)

AVG. ABSOLUTE TEMPERATURE

	Standard deviation		No. Data Pts.
All data	σ =	.025 °K	5

TEMPERATURE DIFFERENCE

Equation of "best line" through shorting ratio data

$$\frac{DTG}{DTA} = .89228 + .000232\ TG$$

Standard deviation from "best line" — No. Data Pts.

(excluding 20° ΔT tests) σ= .0008 °K — 4

EQUIVALENT MEASURING LENGTH

(all data except for tests near zero ΔT)

2X = 17.744 in. ± .043 in.

$$\frac{\text{Equivalent Length}}{\text{Centerline Separation of Sensors}} = .9524 \pm .0023$$

HEAT FLOW PROBE PROGRAM

Bendix Contract SC 0242

Case 68647 5

PERFORMANCE CRITERIA

PROBE HALF F2-2 UPPER

S/N 2230

RING BRIDGE

DATE 1-17-69

AVG. ABSOLUTE TEMPERATURE

EXP. OFFSET. ΔR_B = -.86 Ω (- .43 °K)
(From ADL ΔT Apparatus test data)

Following offset correction:

Standard Deviation

All data σ = .03 °K

TEMPERATURE DIFFERENCE

EXP. OFFSET = -.080 °K ± N.A. °K
(From near zero ΔT tests)

Following offset correction:

Equation of "best line" through shorting ratio data

$$\frac{DTR}{DTA} = .50882 + .000298\ TR$$

Standard deviation from "best line"

(excluding 20°ΔT data) σ = .0012 °K   No. of points 3

LENGTH RATIO (All tests except for those near zero ΔT)

At 225°K

$$\text{Length Ratio} = \frac{\text{Centerline Separation of Sensors}}{\text{Centerline Separation of GT Thermopiles}} = \frac{11.299}{18.684} = .60474$$

$$\text{Shorting Ratio} = \frac{\text{"Best Line" Ratio at 225°K}}{\text{Length Ratio}} = .9523$$

Arthur D. Little, Inc.

HEAT FLOW PROBE PROGRAM

Bendix Contract SC 0242

Case 68647 5

PERFORMANCE CRITERIA

PROBE HALF F2-2 LOWER

S/N 2226

RING BRIDGE

DATE 1-17-69

AVG. ABSOLUTE TEMPERATURE

EXP. OFFSET. ΔR_B = -.84 Ω (- .42 °K)
(From ADL ΔT Apparatus test data)

Following offset correction:

Standard Deviation

All data σ = .035 °K

TEMPERATURE DIFFERENCE

EXP. OFFSET = -.0113 °K ± N.A. °K
(From near zero ΔT tests)

Following offset correction:

Equation of "best line" through shorting ratio data

$$\frac{DTR}{DTA} = .50578 + .000304\ TR$$

Standard deviation from "best line"

(excluding 20°ΔT data) σ = .0006 °K No. of points 3

LENGTH RATIO (All tests except for those near zero ΔT)

At 225°K

$$\text{Length Ratio} = \frac{\text{Centerline Separation of Sensors}}{\text{Centerline Separation of GT Thermopiles}} = \frac{11.279}{18.684} = .60367$$

$$\text{Shorting Ratio} = \frac{\text{"Best Line" Ratio at 225°K}}{\text{Length Ratio}} = .9512$$

8.2 "ΔT Apparatus" Thermocouple Calibration

The following tabulation of values for the four reference gradient tube thermocouples was supplied by Avco Corp., on the basis of calibration data at 0, -38 and -73°C, and is guaranteed to have less than ± 0.1°C error over the calibrated range.

HEAT FLOW PROBE PROGRAM

Bendix Contract SC 0242

Case 68647 ___5___

THERMOCOUPLE CONSTANTS FOR DATA REDUCTION

MODEL: F2   Probe 1 Cable No.: 12   Probe 2 Cable No.: 14

	T in °C	Range
	$C_1 + C_2 (T - T_3)$	250 to 350°K
$EMF_{actual} - EMF_{standard} =$	$C_1 + C_2 (T_2 - T_3) + C_3 (T - T_2)$	200 to 250°K
	$C_1 + C_2 (T_2 - T_3) + C_3 (T_1 - T_2) + C_4 (T - T_1)$	90 to 200°K

Calibration Temperatures (°C): T_1 = -73.116 [B78]* T_2 = -23.119 [B79] T_3 = 76.827 [B80]

THERMOCOUPLE NO.	C_1	C_2	C_3	C_4
11	[B81] = .011384	[B52] = .00012943	[B51] = .00023105	[B50] = .00042462
12	[B82] = .010384	[B55] = .00011142	[B54] = .00023505	[B53] = .00043276
13	[B83] = .010384	[B58] = .00011943	[B57] = .00023305	[B56] = .00042643
14	[B84] = .010384	[B61] = .00011943	[B60] = .00023105	[B59] = .00042733
21	[B85] = .010384	[B64] = .000088416	[B63] = .00021105	[B62] = .00044632
22	[B86] = .010384	[B67] = .000098422	[B66] = .00023905	[B65] = .00045084
23	[B87] = .010384	[B70] = .000098422	[B69] = .00023905	[B68] = .00045084
24	[B88] = .010384	[B73] = .000098422	[B72] = .00023905	[B71] = .00045084

* [ ] denotes designation in input matrix for Arthur D. Little, Inc. data reduction program.

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8.3.2 Generation of Calibration Constants for Reference Junction and Probe Thermocouples

8.3.2.1 Reference Junction

Calibration data from Rosemount Engineering Co. consists of five measurements of bridge voltage ratio (signal voltage to excitation voltage) at five temperature levels. The program fits a cubic equation in absolute temperature (°C) to the voltage ratio data points. The four constant coefficients of the cubic equation are the calibration constants used in subsequent data reduction. This program is written as a spearate routine.

HEAT FLOW PROBE PROGRAM

Bendix Contract SC 0242

Case 66647 5

REFERENCE JUNCTION SENSOR CONSTANTS FOR DATA REDUCTION

Model: F2

S/N: H937

$$\frac{V_o}{V_x} = C_1 + C_2T + C_3T^2 + C_4T^3$$

(T in °C)

C_1 = .38362 E -04 [B46]*

C_2 = .19881 E -02 [B47]

C_3 = -.42347 E -05 [B48]

C_4 = .75079 E -08 [B49]

* [ ] denotes designation in input matrix for Arthur D. Little, Inc. data reduction program.

RECORD OF ACCEPTANCE TESTING
FOR
ELECTRONICS BOX SENSOR
MODEL 118YN
AND
THERMOCOUPLE CABLE
APPENDIX 1
OF
ROSEMOUNT ENGINEERING COMPANY
Procedure No. 16627A

APPLICABLE DOCUMENT
1.3.20

Calibration Temperature (°C)	Bridge Output (Eout/Ein)
0	+0.0000474
+50	+0.089795
Thermally Cycled Three Times From 180°F to -65°F	
-20	-0.041467
0	+0.0000617
+25	+0.047261
+50	+0.089775
+90	+0.150151

Repeatability (Not to Exceed 0.1°C)	
At 0°C	0.0072 °C
At 50°C	0.0123 °C

Insulation Resistance	
Bridge to case is greater than 1000 megohms at 100 VDC	X
Bridge to thermocouple is greater than 1000 megohms at 100 VDC	X
Thermocouple to thermocouple is greater than 100 megohms at 1.5 VDC	X

REC MODEL 118YN S/N H937

THERMOCOUPLE CABLE S/N 12 AND 14.

Rosemount Engineering Co.
Quality Control [signature] Date 3 May 1967

Goverment Represenative [signature] Date 3 MAY 1967

Authur D. Little Inc.
Quality Control Represenative CPBerthiaume Date 10-9-67

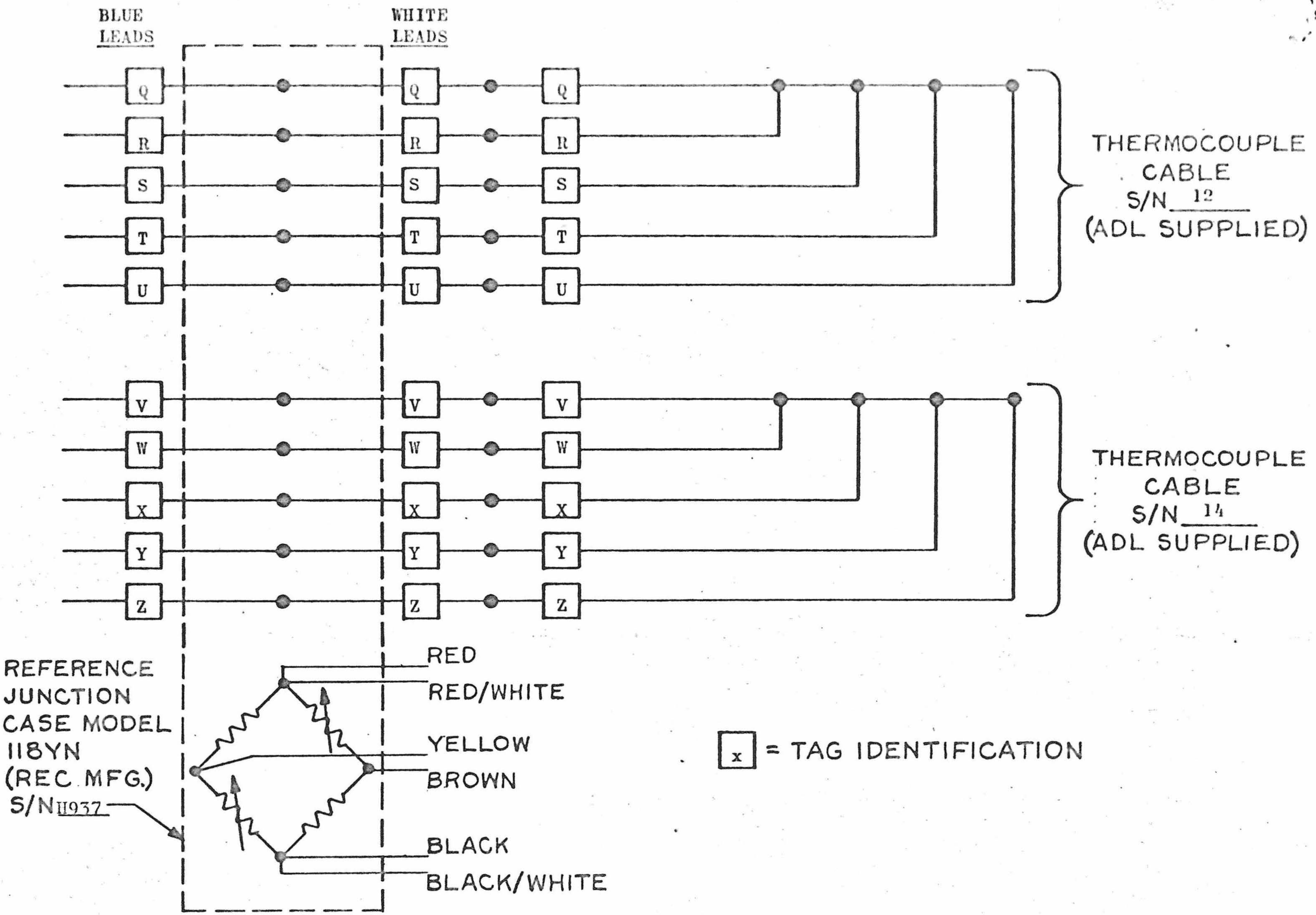
REC MODEL 118YN S/N 11937
THERMOCOUPLE CABLE S/N 12 AND 14

[1] CALIBRATION TEMPERATURE	PARAMETER MEASURED	THERMOCOUPLE LEADS [2]							
		Q to R	Q to S	Q to T	Q to U	V to W	V to X	V to Y	V to Z
90°K	Thermocouple Output (mv)	+8.3381	+8.3381	+8.3381	+8.3378	+8.3390	+8.3390	+8.3390	+8.3361
	Thermocouple Temp. (°C)	-183.71	-183.71	-183.71	-183.71	-183.71	-183.71	-183.71	-183.71
200°K	Thermocouple Output (mv)	+3.9438	+3.9445	+3.9444	+3.9444	+3.9427	+3.9427	+3.9427	+3.9403
	Thermocouple Temp (°C)	-73.116	-73.116	-73.116	-73.116	-73.116	-73.116	-73.116	-73.116
250°K	Thermocouple Output (mv)	+1.3199	+1.3207	+1.3207	+1.3207	+1.3186	+1.3186	+1.3186	+1.3176
	Thermocouple Temp (°C)	-23.119	-23.119	-23.119	-23.119	-23.119	-23.119	-23.119	-23.119
350°K	Thermocouple Output (mv)	-4.786	-4.786	-4.786	-4.787	-4.786	-4.786	-4.786	-4.786
	Thermocouple Temp (°C)	76.827	76.827	76.827	76.827	76.827	76.827	76.827	76.827

[1] Reference junction (Model 118YN) maintained at 0°C.

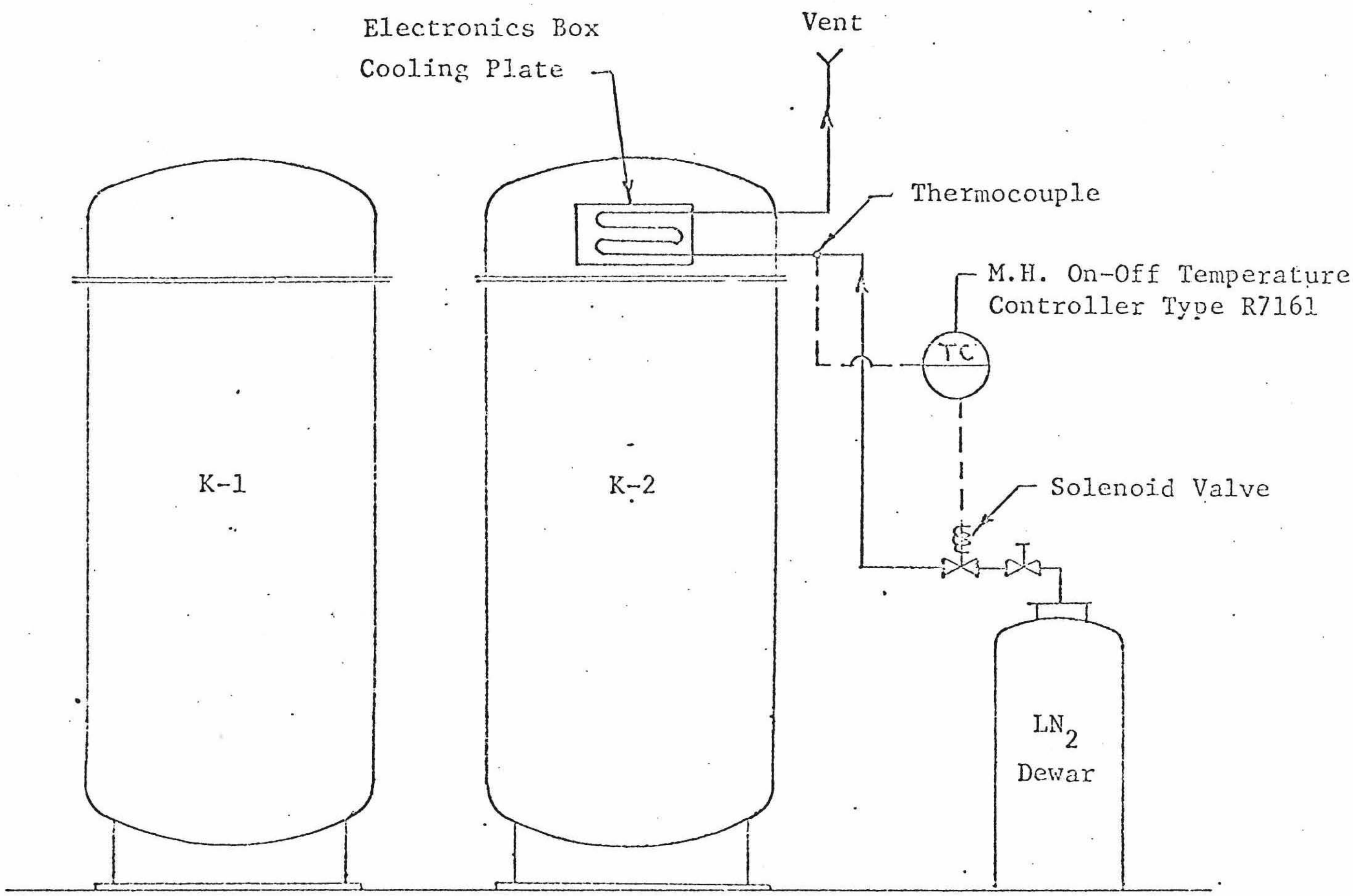
[2] Thermocouple leads identified as Q and V are assigned negative polarity.

ACCEPTANCE TEST DATA SHEET
(THERMOCOUPLE CABLE CALIBRATIONS)



ACCEPTANCE TEST DATA SHEET
(SCHEMATIC DIAGRAM)

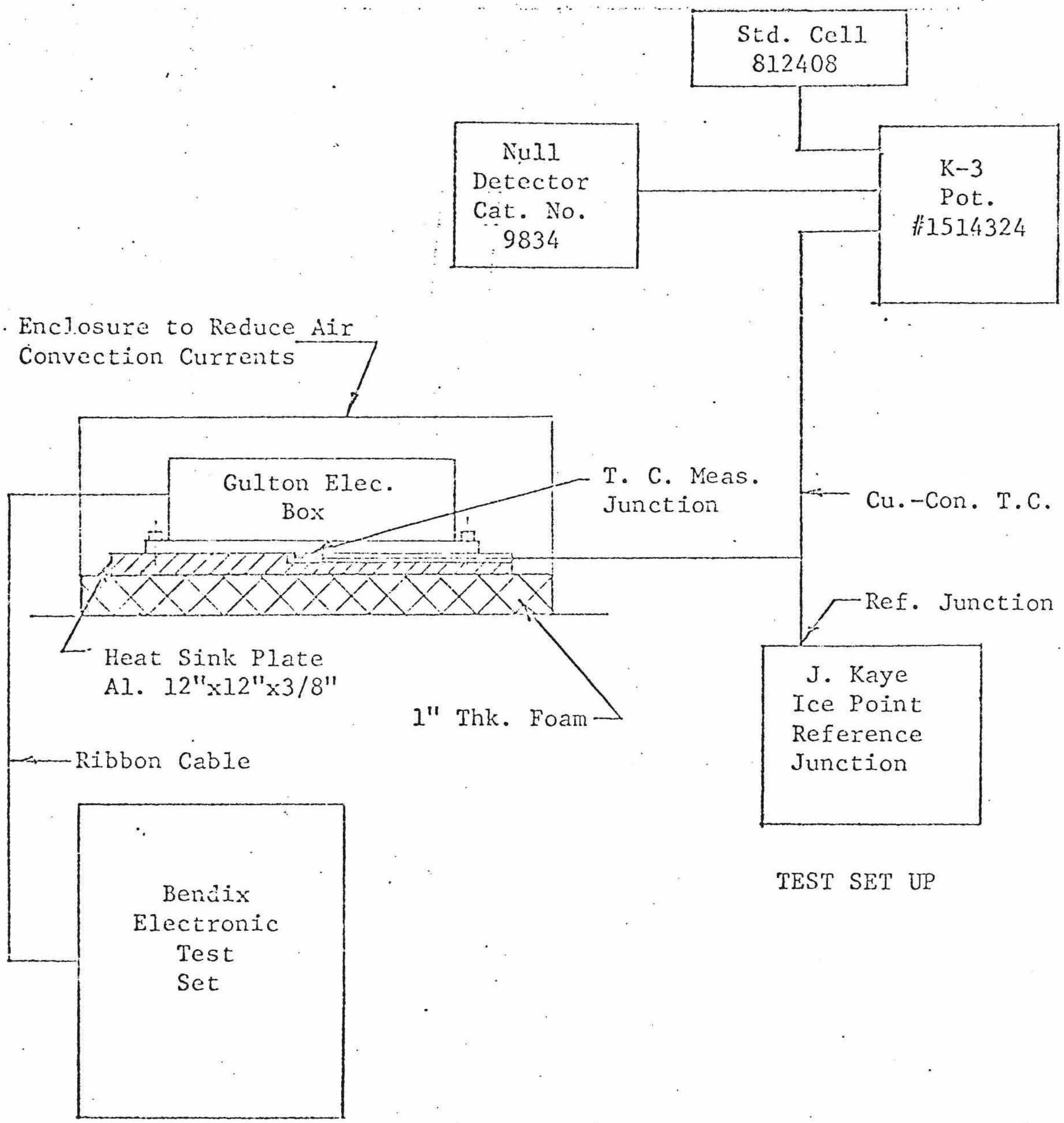
APPLICABLE DOCUMENT 1.3.22



ELECTRONIC BOX COOLING SYSTEM

APPLICABLE DOCUMENT 1.3.23

ELECTRONIC BOX REFERENCE JUNCTION CALIBRATION TEST SET-UP



TEST SET UP

TEST EQUIPMENT USED

Name	Manufacturer	Serial #	Last Calib. Date
K-3 Potentiometer	L&N	1514324	11-67 AVCO
J. Kaye Reference Junct. Mod. No. RCS4	J. Kaye	6974	6-20-67 J. Kaye
Std. Cell, Cat. #100	Eppley	812408	10-23-67 Eppley Labs.
B.A.S. E.T.S.	B.A.S.		
Null Detector	L&N	NONE Mod. #9834	
Calibrated Cop.-Con. T.C.	ADL	NONE	6-67 by AVCO